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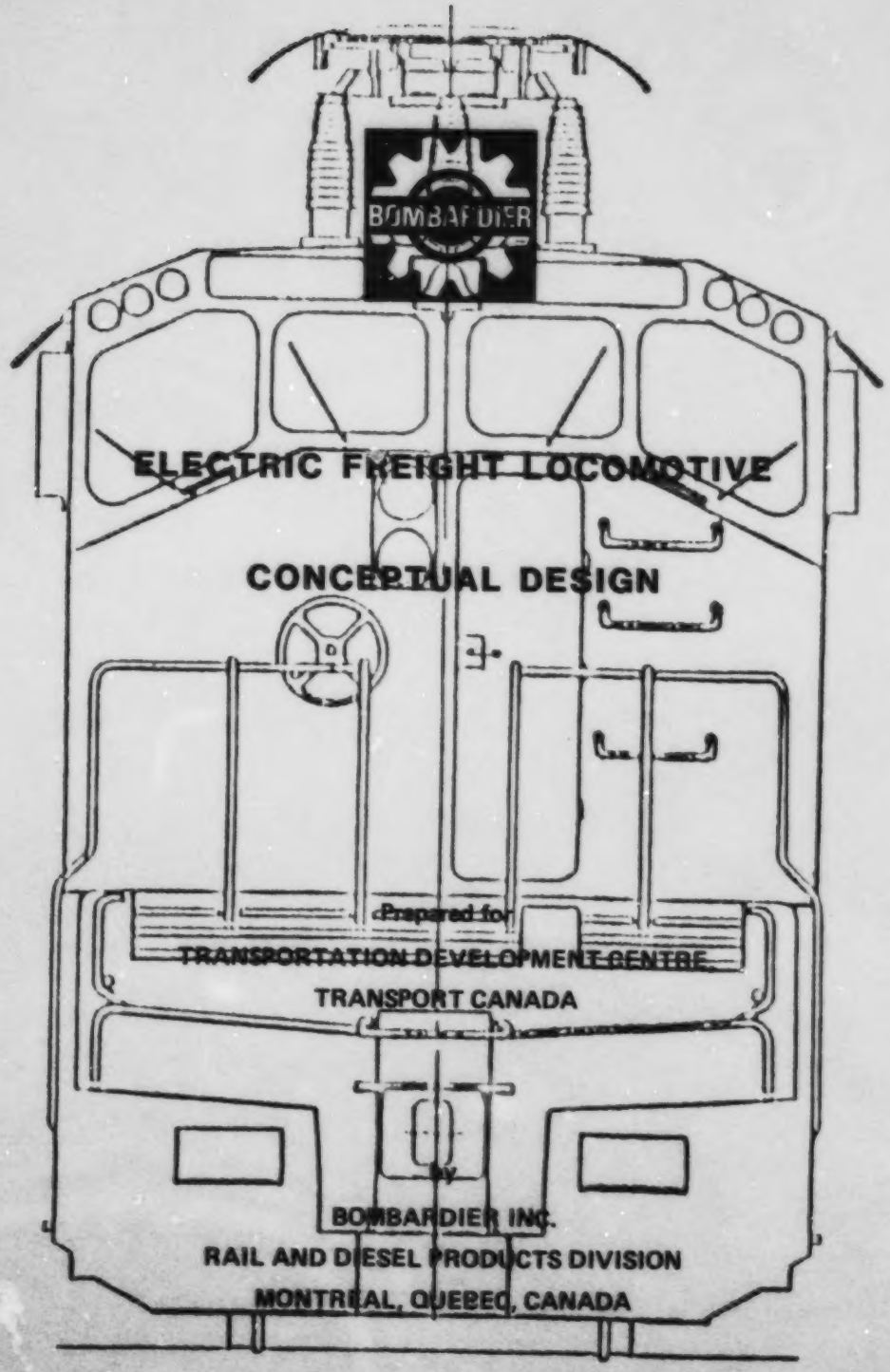

ELECTRIC FREIGHT LOCOMOTIVE

CONCEPTUAL DESIGN

Prepared for

TRANSPORTATION DEVELOPMENT CENTRE

TRANSPORT CANADA

by

BOMBARDIER INC.

RAIL AND DIESEL PRODUCTS DIVISION

MONTREAL, QUEBEC, CANADA

July 1985

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ELECTRIC FREIGHT LOCOMOTIVE

CONCEPTUAL DESIGN

Prepared for

TRANSPORTATION DEVELOPMENT CENTRE,
TRANSPORT CANADA
MONTREAL, CANADA

by H. Dorosh
BOMBARDIER INC.
RAIL AND DIESEL PRODUCTS DIVISION
MONTREAL, QUEBEC, CANADA

July 1985

The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transportation Development Centre, Transport Canada.

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REPORT DOCUMENTATION FORM

1. Transport Canada Report No.	2. TDC Project No.	3. Recipient's Catalogue No.
TP6799E	6023	

4. Title and Subtitle	5. Report Date
ELECTRIC FREIGHT LOCOMOTIVE CONCEPTUAL DESIGN	July 1985
	6. Performing Organization Report No. 439100
7. Author(s) H. Dorosh	8. Transport Canada File No. D1465-402-2
9. Performing Organization Name and Address Bombardier Inc. Rail and Diesel Products Division 1505 Dickson Street Montreal, Quebec H1N 2H7	10. DSS File No. 12SD.T8200-3-3506 11. DSS or Transport Canada Contract No. OSD83-00013
12. Sponsoring Agency Name and Address Transportation Development Centre (TDC) 200 Dorchester Blvd. West, Suite 601, West Tower Montreal, Quebec H2Z 1X4	13. Type of Report and Period Covered June 1983-July 1985 14. Sponsoring Agency Code 6023
15. Supplementary Notes	16. TDC Project Officer C.A. Versailles

17. Abstract

The objective of this study was to analyze future Canadian electric locomotive performance requirements given 50 kV electrification of the main lines and to develop suitable conceptual locomotive layouts.

The study investigated the present locomotives operating on existing 50 kV installations in North America and estimated the tractive effort and power requirements for operating on the main line in Canada. Two requirements emerge: a C-C locomotive capable of 6000 diesel-equivalent hp and a B-B unit suitable for 5000 hp. These locomotives were designed in detail and found feasible with both conventional DC traction and 3-phase AC traction. Preliminary designs of several parts of the locomotive system were prepared.

18. Key Words	19. Distribution Statement
Electric locomotives, traction effort, adhesion, weight transfer, traction motor, trucks, power converters, auxiliary locomotive systems.	Limited number of copies available on request from sponsoring agency

20. Security Classification (of this report)	21. Security Classification (of this page)	22. No. of Pages	23. Price
unclassified	unclassified	121	nil

FORMULE DE DOCUMENTATION POUR RAPPORT

1 Nº du rapport Transports Canada	2 Nº de l'étude — CDT	3 Nº de catalogue du destinataire
TP6799E	6023	

4 Titre et sous-titre	5 Date du rapport
ELECTRIC FREIGHT LOCOMOTIVE CONCEPTUAL DESIGN	Juillet 1985
	6 Nº du rapport de l'organisme executant: 439100
7 Auteur(s): H. Dorosh	8 Nº de dossier Transports Canada: D1465-402-2
9 Nom et adresse de l'organisme exécutant: Bombardier Inc. Division des produits ferroviaires et diesel 1505 rue Dickson Montréal (Québec) H1N 2H7	10 Nº de dossier — ASC: 12SD.T8200-3-3506
	11 Nº de contrat — ASC ou Transports Canada: OSD83-00013
12 Nom et adresse de l'organisme parrain: Centre de développement des transports (CDT) 200 ouest boul. Dorchester Suite 601, Tour ouest Montréal (Québec) H2Z 1X4	13 Genre de rapport et période visée: juin 1983-juillet 1985
	14 Code de l'organisme parrain: 6023
15 Remarques additionnelles	16 Agent de projet — CDT: C.A. Versailles

17 Résumé

Ce rapport rend compte de l'étude faite pour analyser les besoins futurs au Canada en matière de traction ferroviaire électrique, dans l'optique d'une électrification des grandes lignes sous 50 kV, et pour définir une locomotive électrique de puissance appropriée.

La recherche a porté sur les locomotives électriques alimentées sous 50 kV en service en Amérique du Nord et sur les puissances et les efforts de traction à mettre en oeuvre dans le cas d'une électrification du réseau canadien. La recherche a débouché sur les résultats suivants: nécessité d'une locomotive CC et d'une locomotive BB d'une puissance de 6 000 et de 5 000 hp équivalents diesel, respectivement. Etudiées dans le détail, ces locomotives se sont révélées réalisables en alimentation tant continue que triphasés. L'avant-projet de plusieurs organes a été réalisé.

18 Mots-clés	19 Diffusion
Locomotives électriques, effort de traction, adhérence, délestage, moteur de traction, bogies, convertisseurs, organes de locomotives.	Le CDT dispose d'un nombre limité d'exemplaires.

20 Classification de sécurité (de ce rapport)	21 Classification de sécurité (de cette page)	22 Nombre de pages	23 Prix
non-classifié	non-classifiée	121	nil

SUMMARY

This report summarizes work carried out by Bombardier Inc. to examine the performance requirements for an electric locomotive suitable for operation on future mainline Canadian railroads electrified at 50 kV AC 60 Hz.

It was found that such an electric locomotive would have a tractive effort comparable to modern diesel-electric locomotives but significantly increased power capabilities - 5000 continuous diesel-equivalent hp in a general-purpose 4-axle locomotive and 6000 diesel-equivalent hp in a 6-axle unit to be used primarily in steeply-graded terrains.

Layouts of B-B and C-C locomotives with various hood, cab, and traction system alternatives were carried out. A conventional drive using separately-excited DC motors and a drive based on the use of 3-phase AC asynchronous traction motors would be the preferred traction systems. The electric locomotives can be readily derived from existing diesel electric locomotive models.

Special areas unique to electric locomotive design were subjected to preliminary design work in the study. Particular attention was paid to roof strengthening and removal due to the presence of 50 kV electric components on the roof.

A rough comparison made of the cost of locomotive builder-supplied labor and materials revealed a lower cost than for diesel-electric locomotive manufacture. The overall locomotive first cost, however, will be higher than a diesel-electric when the bought-in electrical equipment is included.

SOMMAIRE

Ce rapport rend compte de la recherche faite par Bombardier Inc., en vue de définir les performances devant être affichées par une locomotive électrique utilisable dans l'avenir sur un réseau ferroviaire électrifié canadien, alimenté sous 50 kV à 60 Hz.

La recherche a montré que la locomotive électrique aurait un effort de traction comparable à celui des locomotives diesel-électriques actuelles, mais développer une puissance beaucoup plus élevée, à savoir 5,000 hp équivalents diesel dans le cas d'une locomotive polyvalente à 4 essieux et 6,000 hp dans le cas d'une locomotive à 6 essieux pour la traction sur rampes prononcées.

Divers schémas d'aménagement ont été etudiés sur les locomotives BB et CC, y compris le pavillon, la cabine et la chaîne cinématique. La chaîne à préconiser comporterait des moteurs à courant continu et à excitation séparée ou des moteurs asynchronés à alimentation triphasée. Enfin, l'architecture générale dériverait de celles des loco motives diesel-électriques existantes.

Les caractéristiques propres aux locomotives électriques ont fait l'objet d'une étude d'avant-projet, notamment le pavillon qui devra être amovible afin de permettre l'accès aux organes électriques et renforcé pour pouvoir supporter les appareillages à 50 kV.

Le devis estimatif établi montre que le coût en matériel et main d'oeuvre pour une locomotive électriqueserait inférieur (prix de l'équipement électrique non compris) à celui d'une locomotive diesel, mais que le coût total dépasserait le prix de cette dernière.

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1. INTRODUCTION

1.1 Background

Electric locomotives are manufactured in North America in relatively large numbers only for service on the Northeast Corridor in the United States. In the past few years these have all been units designed to work passenger trains. Freight locomotive sales have been restricted to a few units each at widely-separated special operations such as Texas Utilities, Black Mesa, Muskingum, Deseret-Western, and, most recently, the Tumbler Ridge branch line of BC Rail. Characteristic for all these applications was operation at the industrial frequency common to North America, 60 Hz, and the elevated line voltages of 25 and 50 kV.

Although builders have attempted to channel electric locomotive development into a design applicable to the mainstream of expected operator requirements for the time when electrification arrives on a large scale, the actual applications have resulted in widely divergent locomotive designs.

The Transportation Development Centre has recognized a need to determine the actual range of potential electric locomotive requirements in Canada and for a manufacturer to generate conceptual designs for a selected few locomotives to satisfy these requirements.

Bombardier expressed an interest in participating in such a study as they have manufactured diesel-electric locomotives in Canada for the domestic and international market for many years and were eager to expand into electric locomotive manufacturing if a suitable market becomes available.

Given the long expected life of electric locomotives it was judged essential to incorporate equipment using the most modern technology.

Electrification studies have established the feasibility and desirability of a 50 kV, 60 Hz electrification system and it was for this system voltage that the designs were carried out. This was done with the understanding that conversion of the designs for 25 kV operation could be easily accomplished if future studies should indicate superior benefits for specific 25 kV applications.

Appreciable contributions to the study were made by personnel at BBC-Brown Boveri Canada Inc., and GEC Transportation Projects Ltd., in the areas of 3-phase AC and DC traction technology respectively. These were the only suppliers of traction equipment who responded in sufficient depth to make a meaningful contribution to this study.

1.2 Objectives

The objectives of this study were to define standardized requirements for electric locomotives to operate in future Canadian electrified mainline freight service and carry out conceptual locomotive designs based on these requirements.

Standardization to a limited number of designs is very desirable for both the manufacturer and railroad operator because of the economies that can be realized in designing, manufacturing, operating, and maintaining the locomotives.

For any set of locomotive performance criteria a number of locomotive designs can be devised to meet the requirements. Clearly, however, some of the designs may be impractical for technical and/or economic reasons. An intermediate objective of this study, therefore, was to determine which locomotives were generally feasible and to proceed to more detailed designs with only the potentially most popular of these.

1.3 Methodology

The methodology used in achieving the objectives of the study was as follows:

- Define locomotive performance criteria. Study locomotive arrangements and equipment alternatives based on the criteria.

- Identify feasible locomotive layouts and, where required, modify the performance criteria.

- Develop locomotive specifications.

- Develop locomotive conceptual layouts for important applications including preliminary design of some locomotive subsystems. Where required, modify the performance criteria.

- Determine compatibility of the layouts with actual existing locomotive manufacturing procedures and experience. Assess whether the manufacturing process or the locomotive design would have to change.

- Develop manufacturing costs.

- Organize information exchange with principal subcontractors and involve them in the design process.

This was an iterative approach requiring extensive drafting work at a conceptual level and frequent information exchange with locomotive equipment vendors. The end result is a series of locomotive layouts suitable for submission as the technical basis of proposals for the most important potential Canadian mainline freight applications.

2. LOCOMOTIVE PERFORMANCE CRITERIA

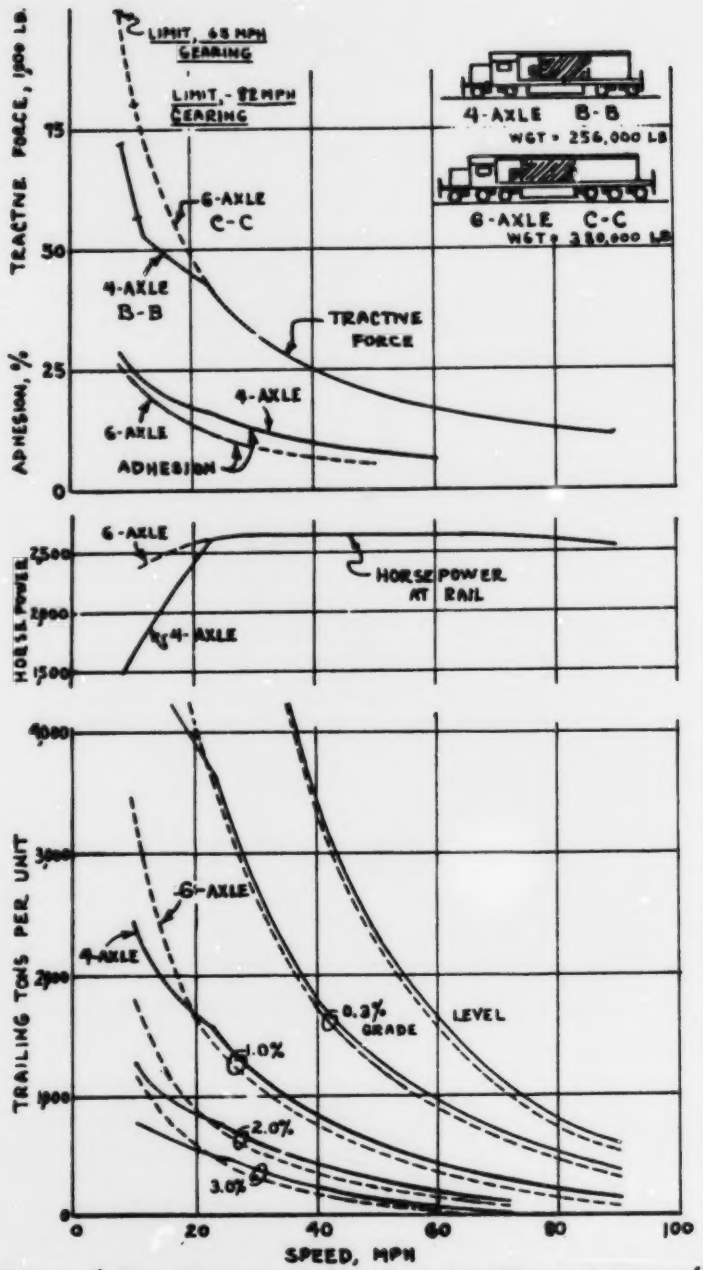
2.1 Locomotive Tractive Effort

In existing railroad operations in North America no attempt is usually made to define locomotive performance when requesting proposals for supply of new diesel-electric locomotives. Due to the uniform nature of Canadian and U.S. railroading and the evolutionary development of diesel-electric locomotives in the past 40 years such locomotives are invariably specified by simple reference to traction horsepower requirements and axle configuration (B-B or C-C). By long familiarity with older models of the same builder's locomotive the railroad could easily predict the tractive effort capability of a new locomotive. Road trials and/or operating experience enabled the railroad to assign a tonnage rating to the locomotive for a given service. Interestingly, railroads could readily make up train consists by knowing simply the locomotive designation (this gives the traction power and axle configuration) and its minimum continuous speed (an indication of the gearing employed). Figure 1 depicts some of these relationships [1].

A high power train requirement necessitates the use of multiple diesel-electric locomotives throughout a train. For mountainous terrain the presence of numerous driven axles results in a low demand on available adhesion - an advantageous situation considering the marginal performance of older locomotive wheel-slip systems.

In the last two decades engine power capabilities have risen steadily and the same train can now be hauled by fewer locomotives. When heavy grades are encountered, however, greater demands are placed on utilization of available adhesion, and wheel-slip systems have become the object of continued improvements. Concurrently,components of the drive system are now increasingly stressed in terms of power and tractive effort and have consequently required continued upgrading.

These changes are starting to find entrance into railroad specifications in the form of requirements for wheel-slip control allowing exploitation of available adhesion into the 24-26% range and traction equipment capable of accepting the higher traction current and transmitting the required forces.



From " The Railroad–What It Is–What It Does "
By J. Armstrong

Figure 1. Locomotive Performance Parameters

The electric locomotive can be likened to a diesel-electric with an engine-alternator set of practically infinite power removed to a trackside location. This perception has led to the concept of "equivalent diesel hp" in describing the continuous power capability of an electric locomotive. Figure 2 shows schematically, for a diesel-electric and electric locomotive of identical delivered rail power, the allocation of engine and pantograph power respectively. "Diesel equivalent hp" can be seen to be that value of power required on a "typical" diesel-electric locomotive to realize the same rail power as the electric locomotive. This value has no physical significance on the electric locomotive. Its usage is also imprecise because it depends on the assumed efficiency of the "typical" diesel-electric locomotive, which will vary between makers and models. Notwithstanding these objections, its usage is quite common in North America when describing electric locomotives to operators with only diesel-electric locomotive fleet experience and will also be used in this report.

Relegating the prime mover function to the trackside results in replacement of the engine, alternator, and fuel, lubrication, and engine cooling systems by a significantly lower weight assembly of electric locomotive components. This can be exploited to lower axle loadings (or number of driven axles) and/or allow installation of more powerful electrical and drive components to dramatically increase rail power vis-a-vis diesel locomotives [2].

In passenger service the electric locomotive will exploit both these possibilities. Axle loading and number of axles are kept low to minimize track damage at high speed. Installed power capability is high (5,300 hp for the AEM-7 on the Northeast Corridor, for example), in order to achieve high train speeds against a predominantly aerodynamic resistance [3].

In freight service adhesion becomes the primary consideration for any but the most flat terrain and sufficient "adhesion weight" must be provided to reliably haul heavy trains. The equipment weight added in order to have increasingly larger installed power levels is, therefore, not a major concern for a North American electric freight locomotive and a unit has already been built for 10,000 diesel equivalent hp in a six axle configuration without exceeding the allowable axle load or requiring special body construction practices [4].

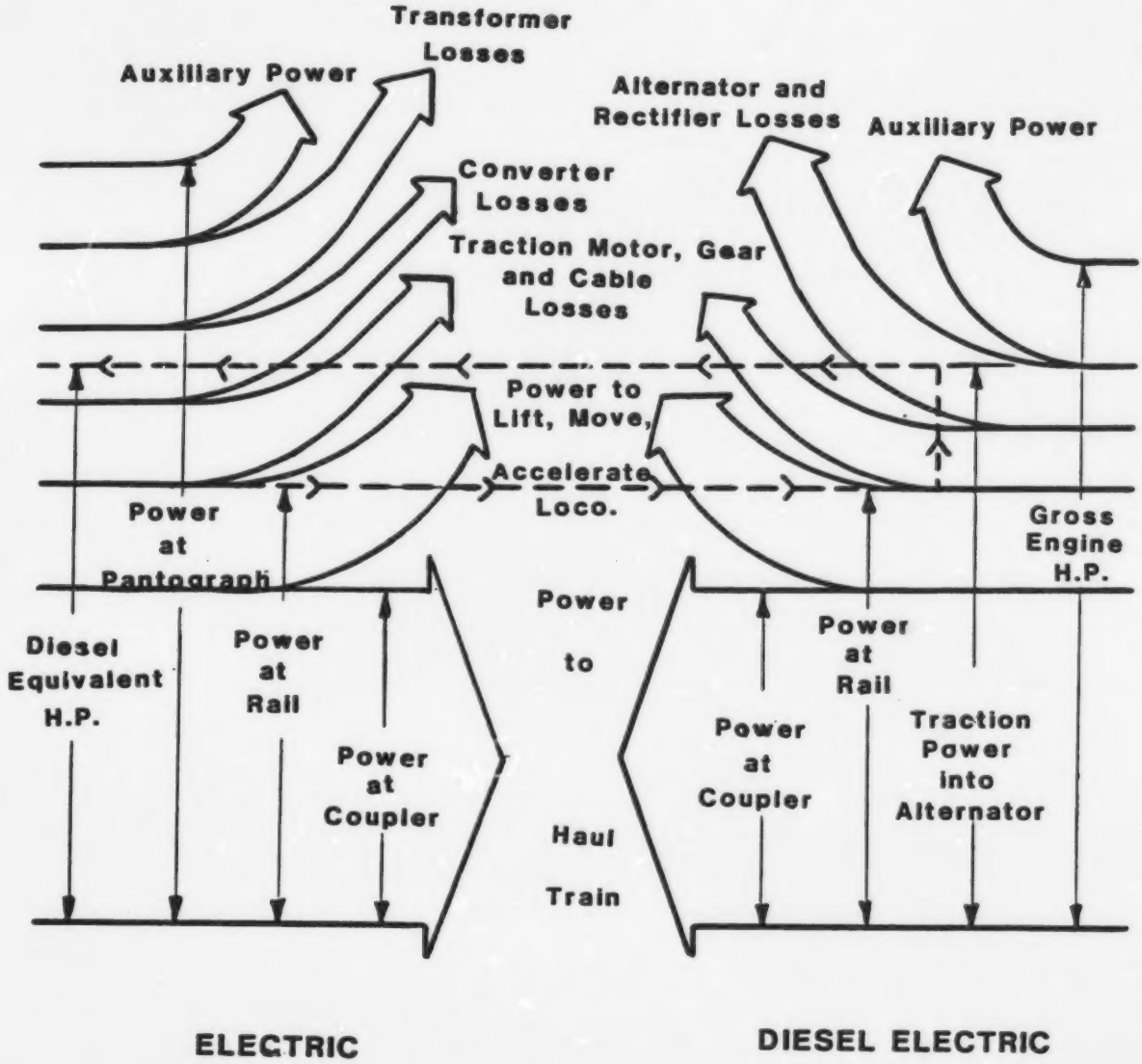


Figure 2. Comparison of Electric and Diesel Electric Locomotive Power Ratings

The degree of similarity of traction equipment and trucks between electric locomotives and diesel-electrics is, however, a function of the power installed, with the result that below about 1000 diesel-equivalent hp per axle these items can largely be retained in some form. Above this power level special motors, drives, and trucks may be required.

To conform to North American practices electric freight locomotives will be considered to have the same axle loading as the common North American diesel-electric freight locomotive; i.e. 60,000 to 70,000 lbs per axle.

The dispatch adhesion in Canada for heavy freight trains has historically been in the range of 18 to 20% and can be raised to 24-26% for locomotives equipped with adequate wheel slip control systems and traction components sized to continuously handle the resulting traction forces.

Dispatching a train at high adhesion levels increases the risk of stranding a train because:

- there is always a possibility - the probability of which varies with season, weather, and numerous other uncontrollable factors that the adhesion required is simply not available.

- loss of a locomotive in a consist may result in excessive adhesion demands on the remaining units.

Inability to complete a train movement on a grade blocks the track and is highly undesirable for this reason and because of the subsequent operating measures required to remove the train. It serves no purpose, therefore, to design the locomotive traction system (either electric or diesel-electric) to generate more tractive effort <u>continuously</u> at the rail than called for by the product of dispatch adhesion and allowable maximum axle loading. The limit for a 4-axle locomotive would be typically 4 x 65,000 x .26 = 67,600 lbs. and for a six-axle 101,400 lbs.

2.2 Tractive Effort Control

2.2.1. Wheel Rail Slip Characteristics

The actual tractive effort transmissible for a given wheelset depends on the slip characteristic of both the traction drive system and the wheel-rail interface. The former depends on the torque-speed characteristics of the traction motors used on the locomotive, the type of power circuit applied, and the design of the controls.

The wheel-rail slip characteristics are dependent on the momentarily existing adhesion at the wheel-rail interface and the axle loading. These characteristics are shown conceptually in Figure 3a where it can be seen that to transmit a force F at the wheel-rail interface a slip of $S = (V_w - V_v)/V_v$ will be required.

The same characteristics are plotted on a slip basis as Curve a in Figure 3b. Curve b has been added to show the result of reduced weight on the axle and Curve c to show the effect of reduced available adhesion. If it is assumed that Curves a, b, c represent the slip characteristics under three different wheelsets of a locomotive and that the traction drive characteristic of each wheelset is identical then it is obvious that the overall locomotive tractive effort will not divide equally among the various wheelsets and that the individual slips may vary widely.

2.2.2. Weight Imbalance and Transfer

In order to have equitable sharing of tractive effort between axles it is desirable to minimize weight imbalance and transfer. Imbalance is controlled during design and construction of the locomotive to about a plus /minus 2% difference between trucks.

Weight transfer between axles within a truck can change the effective load on an axle by 20% or more. The elevated position of the coupler relative to the wheel-rail contact point forms a couple which results in truck-to-truck weight transfer. The trucks, themselves, can also tilt if the point of effective force transmission in the trucks is above the top of the rail, resulting in weight transfer between the axles. These weight transfers are interactive, as can be seen from Figure 4 for the case of a 4-axle locomotive. The load on a given axle is increased or decreased by the product of the locomotive tractive effort per axle multiplied by the weight transfer coefficient for that axle.

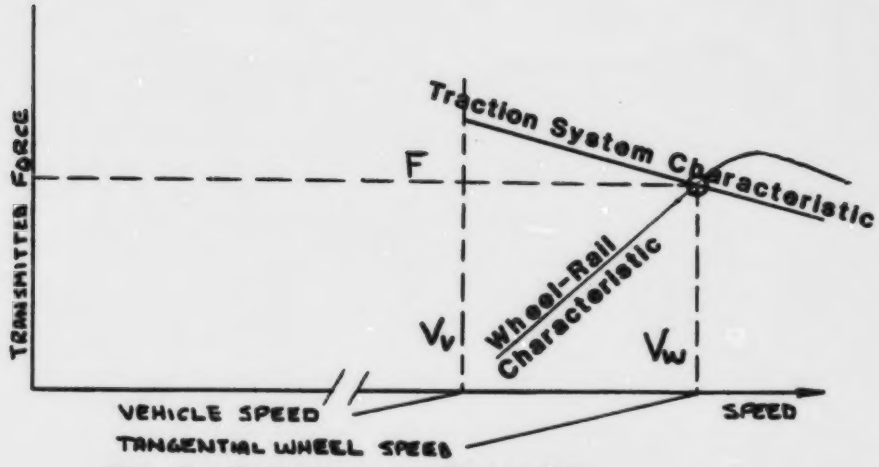


Fig. 3a Definition of Wheel Slip

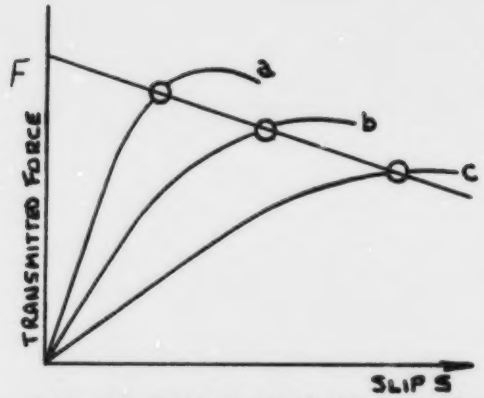


Fig. 3b Effect of Axle Loading and Rail Condition

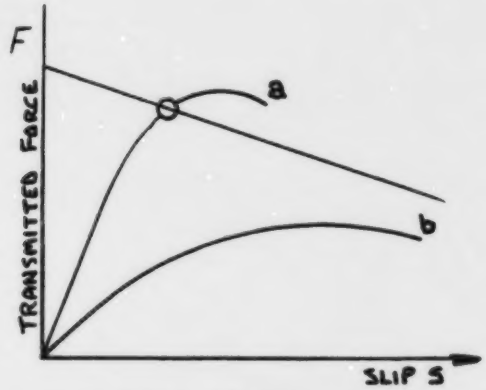


Fig. 3c Runaway Slip

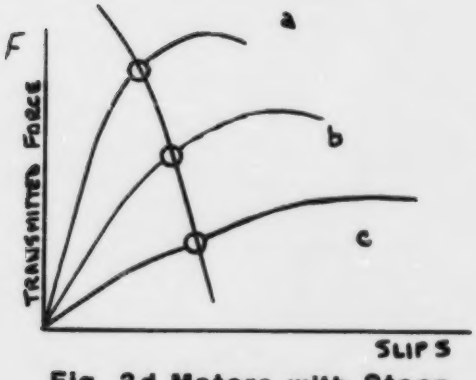


Fig. 3d Motors with Steep Characteristics

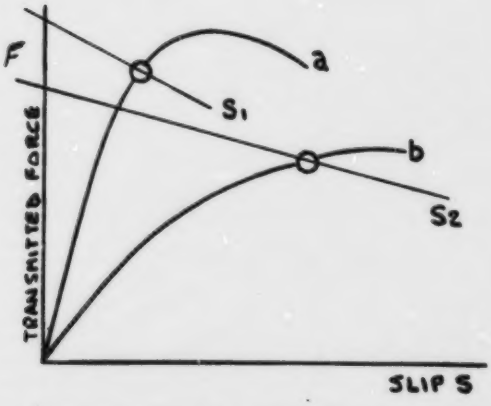
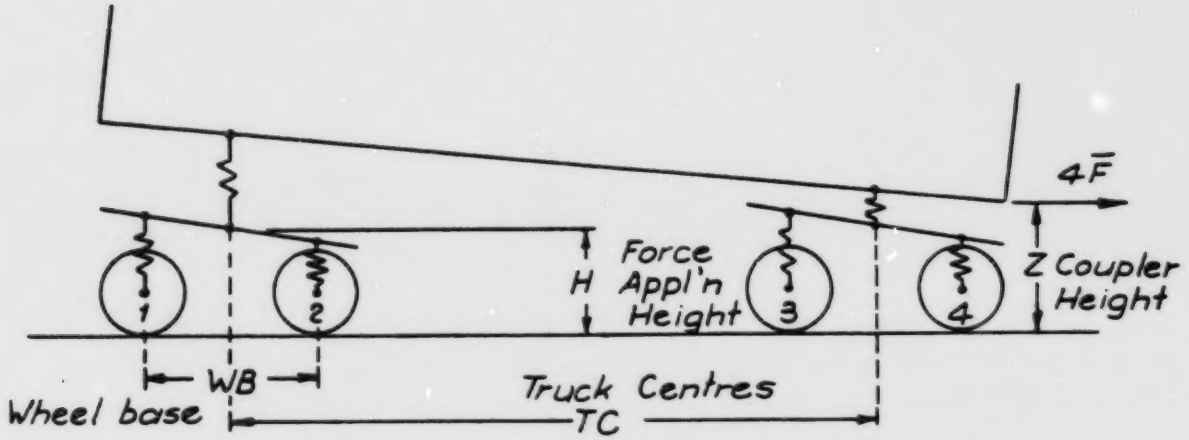


Fig. 3e Individual Axle Control

Figure 3. WHEEL-RAIL FORCE TRANSMISSION



$$WT_1 = -2\left(\frac{H}{WB} + \frac{(Z-H)}{TC}\right) \qquad WT_2 = 2\left(\frac{H}{WB} - \frac{(Z-H)}{TC}\right)$$

$$WT_4 = 2\left(\frac{H}{WB} + \frac{(Z-H)}{TC}\right) \qquad WT_3 = -2\left(\frac{H}{WB} - \frac{(Z-H)}{TC}\right)$$

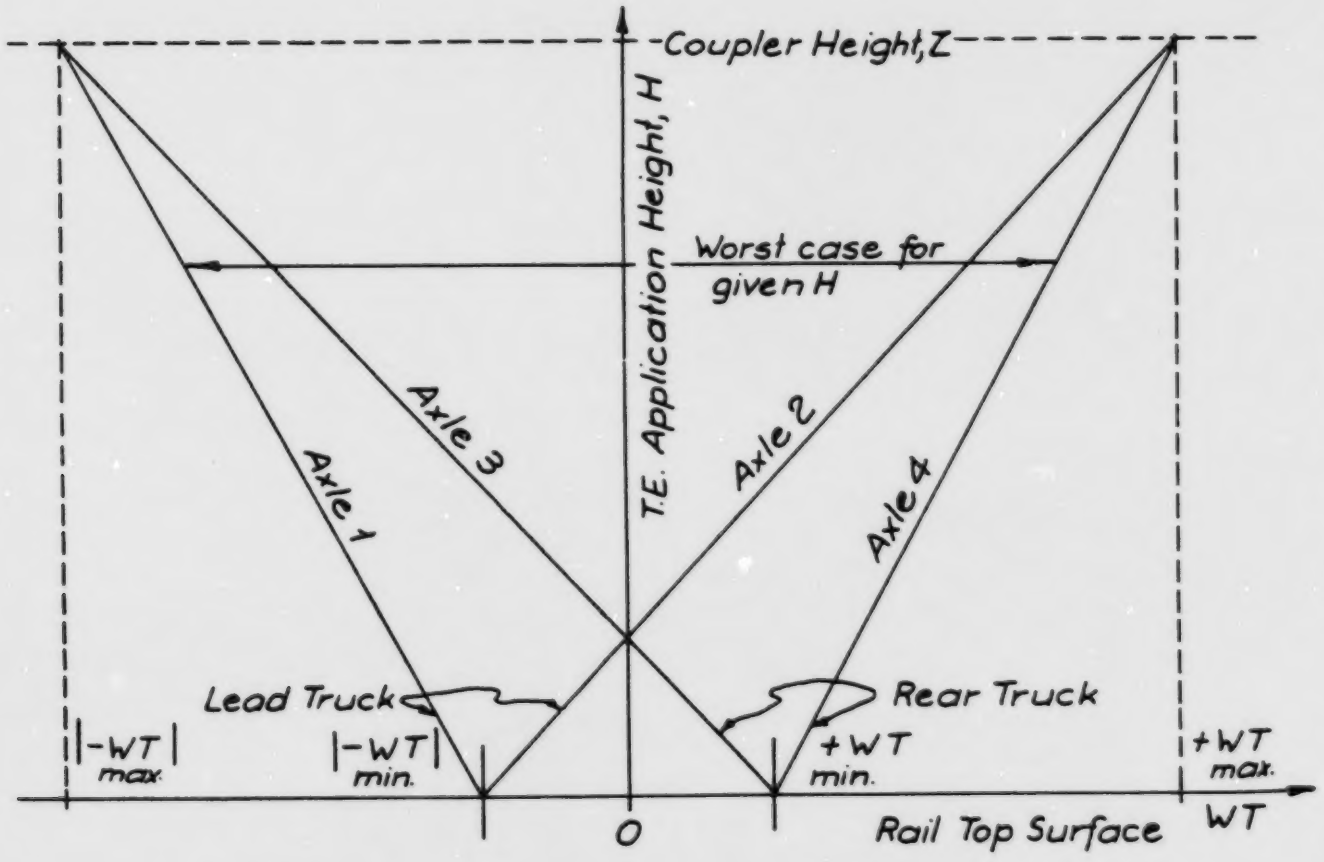


Figure 4. WEIGHT TRANSFER COEFFICIENTS

Weight transfer effects cause leading axles in each truck to carry a reduced portion of the locomotive weight. When, as in the case of all North American diesel- electric locomotives, there is only one controller, the same voltage is applied to all the traction motors in parallel and the resulting adhesion demand at the leading wheelset will be significantly greater than on the other wheelsets. Increased wheel-rail slip will be experienced at the leading wheelset with a consequent tractive effort redistribution among the other traction motors.

If traction motors fed from a common controller have a relatively flat tractive effort-slip characteristic, large slips can develop before significant motor back-EMF is available to reduce motor current and hence, tractive effort at a lightly loaded wheelset. Under poor rail adhesion conditions it may be impossible for the lightly-loaded wheelset to transmit the available force and runaway slip results (Figure 3c, Curve b). Uncontrolled spin of the wheel on the rail is damaging to wheels, rails, and traction components. The onset of runaway slip is detected in a locomotive wheel slip control system and various measures applied to prevent the slip from increasing beyond acceptable limits.

If traction motors supplied from a common controller have a steep instead of a flat characteristic it becomes much more unlikely that an individual axle can develop a runaway slip. This is shown conceptually in Figure 3d for axle loading and rail condition curves similar to those shown in Figure 3b. It is clear in this case, however, that larger differences in transmitted force will develop among the wheelsets. The tractive effort lacking at some wheelsets experiencing unloading due to weight transfer and poor rail adhesion conditions will be compensated by increased traction effort demanded from the more heavily loaded wheelsets. This potential overloading, of course, must be considered in the design of the traction drive components.

2.2.3 Weight Transfer Compensation.

Weight transfer between axles in a truck can be eliminated mechanically by:

- adding and subtracting appropriate external forces to the front and rear of the truck as a function of coupler force.
- eliminating the resulting vertical component of the force transmission vector in the truck.

One implementation of the first method makes use of cables and pneumatic cylinders to generate forces between the truck and locomotive frame [5]. The second method is implemented on numerous 4-axle locomotives by using either inclined traction links or angled chevron pads.

Actuator-based weight transfer correction results in a more complicated and expensive truck both in purchase and maintenance and has not found acceptance in North America. Angled chevron force transmission is readily implemented, however, and has been accepted for use on many 4-axle loco- motives in North America to include the VIA LRC diesel-electric locomotives.

Six axle locomotives will often use a hard secondary suspension and traction motors all facing in one direction to reduce truck pitching and axle-to-axle weight transfer in a truck. This may be applicable to 4-axle locomotives as presented in the TDC Report Design and Evaluation of 2-Axle Steerable Locomotive Trucks [6], from which a truck drawing is presented in Figure 5.

As can be seen from Figure 4, when the weight transfer effect in each truck is completely compensated there will remain a truck-to-truck weight transfer component (WT min) which cannot be eliminated. Adjustment of individual motor currents can be used, however, to eliminate the effects of this remaining weight transfer. An appropriate controller must be provided for each truck in order to slightly reduce traction motor current in the motors of the leading truck while the current in the motors of the trailing truck are slightly increased. The overall effect will be that all axles will work to the same adhesion utilization level and the tractive effort output of the locomotive will be maximized.

Controllers can also be assigned on a per-axle basis, whereby each individual wheelset can be separately controlled to compensate all weight transfer effects. As portrayed conceptually in Figure 3e, each wheelset is characterized by a different traction system characteristic (instead of motor characteristic) that adapts to the existing conditions at each wheel-rail interface by attempting to maximize the transmitted force.

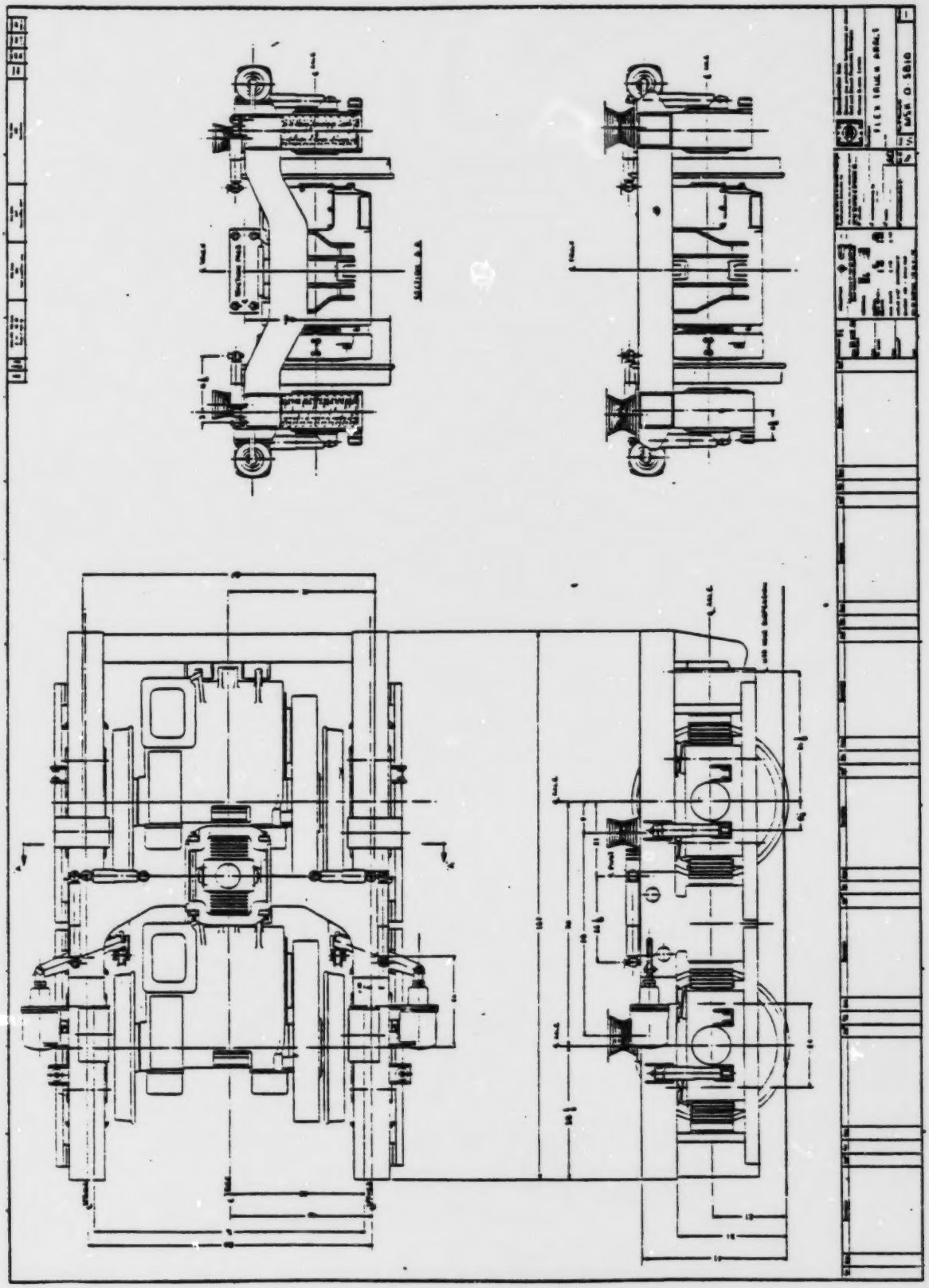


Figure 5. FLEX TRUCK ARRANGEMENT

Typically electric locomotives are provided with controllers on a truck or individual-axle basis, as opposed to present North American diesel-electric locomotives where only a single controller (alternator field excitation) is used. Multiple controllers can be incorporated into diesel-electric locomotives but would represent additional expense, weight, and volume, for a modest performance gain whereas such controllers are inherent to the electric locomotive traction power system.

2.2.4 Rail Condition

Wheel-rail adhesion can vary between clean, dry conditions (adhesion factor $>.40$) under which even the overload tractive effort capability of the locomotive cannot bring the wheels to spin on the rail, and wet, oily conditions (adhesion factor $<.10$) where locomotive operations become very impaired. For the majority of the time tractive effort transmission can be accomodated by wheel slip less than approximately 1.5%. The wheelslip system can, however, also be designed to allow slips of up to 15% before reducing power [7]. This is beneficial on oily track since the adhesion maximum under these conditions occurs at high slip values. In addition, slip of the leading wheelset on the rail creates improved adhesion conditions for the following wheelsets due to the cleaning action of the slipping wheels. An absolute speed reference for the locomotive is required for operation at large slip. A number of electric and diesel-electric locomotives are now operating in North America with an on-board radar for this purpose.

2.2.5 Tractive Effort Control Requirements

The requirements for the tractive effort control of a Canadian electric freight locomotive are as follows:

- minimization of weight transfer in the trucks.
- compensation of remaining weight transfer by electrical compensation on a per-truck or per-axle basis.
- wheel slip system suitable for operation in both low-slip and high-slip regions using a ground speed reference

2.3 Locomotive Traction Power

2.3.1 Usability Considerations

The usefulness of increased locomotive power to the railroad operator depends on the applicability of the following potential benefits:

- decreased time for a train movement.

- increased effective track capacity.

- fewer locomotives.

Greater locomotive power capability acts to maintain tractive effort to a higher speed. This can be seen from Figure 6a where the minimum speed for continuous power is assumed to be Point A for a diesel-electric and Point B for an electric locomotive assuming similar trucks and drive components. Under overload conditions the diesel electric is limited by the installed engine capacity (Point A') while the electric can draw on the power system (Point B') to maintain tractive effort. The result is a greatly enhanced capability of electric locomotives to accelerate trains in the medium-to-high speed range. This is especially important where curves and hence numerous speed restrictions are prevalent.

On some grades the introduction of electric locomotives to replace equal numbers of diesel-electrics will allow significantly higher train speeds. Figure 6a illustrates this for Grades No. 1 and 2 where train speeds are increased from Points E to F and C to D respectively. Grade 3 represents a border-line condition where the continuous performance of electrics and diesel-electrics would be equal (Point A). The overload capability of the electric may, however, allow operation of the train up to a much higher speed (Point B''), adhesion and speed limits permitting.

Increased locomotive power may also allow reduction in the number of locomotives in a consist. On level or lightly graded track, diesel-electrics can be replaced by electrics in proportion to their continuous power capabilities.

This advantage disappears, however, when entering segments containing grades sufficiently severe that the consist becomes adhesion-limited; i.e. locomotives must be added to the electric locomotive consist in order to put sufficient adhesion weight on the rail to climb the grade at normal adhesion levels.

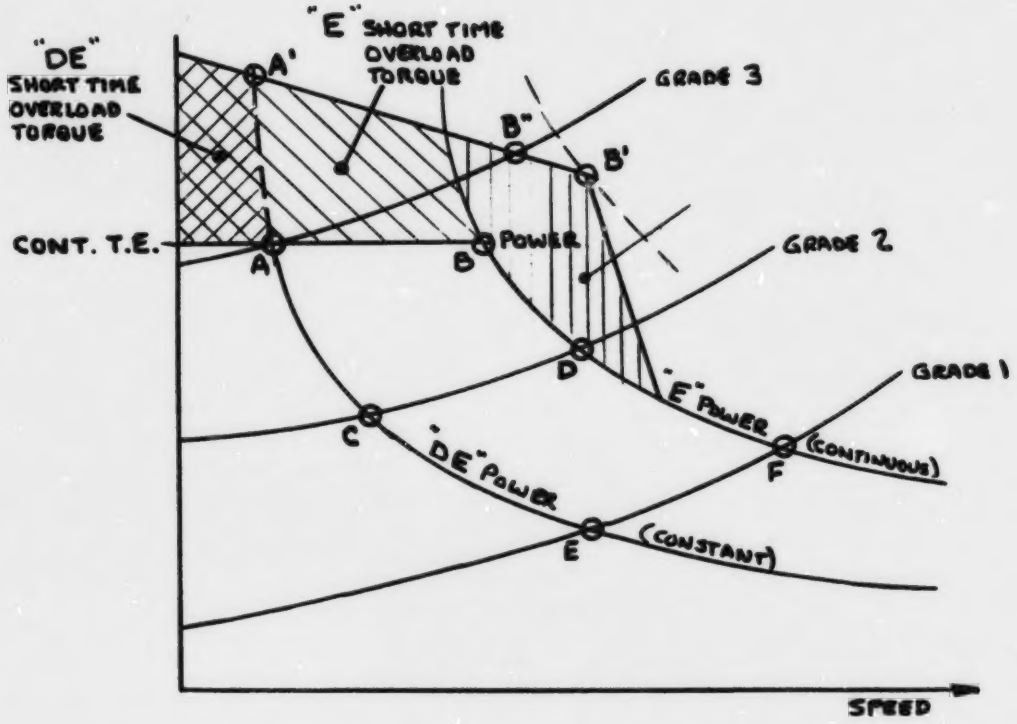


Figure 6a. Representation of Continuous and Overload Power

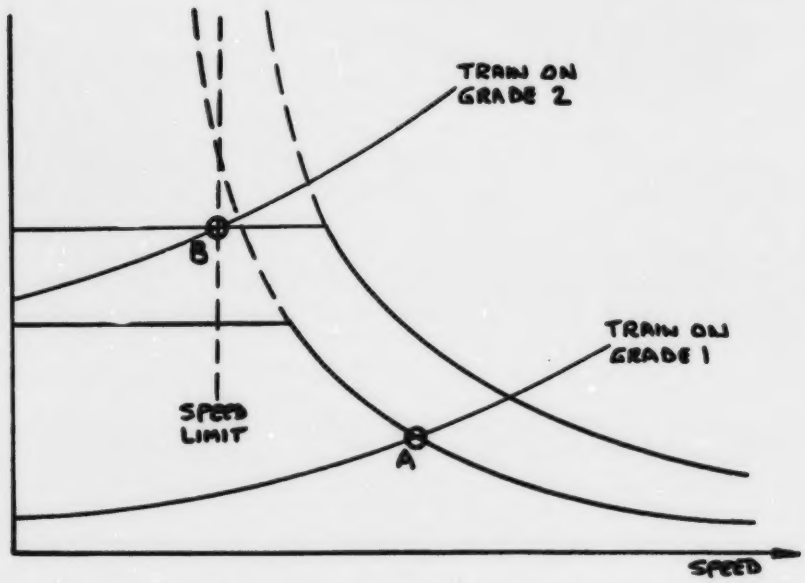


Figure 6b. Helper Operation

Figure 6. TRACTIVE EFFORT CHARACTERISTICS

The power capability of the electrics would, in this case, be considerably underutilized. This is represented in Figure 6b where Point A represents operation of a train with an electric locomotive consist in lightly-graded territory (Grade 1). On a more severe grade (Grade 2) insufficient continuous tractive effort would be available to climb the grade with this consist (overload tractive effort cannot be relied upon since very high adhesion demands would be required). Helper units would be added in order to realize Point B. Depending on the local speed limit, the helper units could be of relatively low power as long as they produced the requisite tractive effort. In the case depicted the power requirements of the augmented consist do not even equal those of the original consist capabililty.

2.3.2 Canadian Railroad Requirements

The power to be installed in an electric locomotive for Canadian mainline application has been intensively researched [8]. It has been found that on some segments of the CN and CP systems an overload capability in excess of 2500 hp/axle could be useful in increasing the average speed of some types of trains. It has been realized, however, that most of the benefit will occur for power in the 1000 to 1500 hp/axle range.

To determine the continuous power capability required by an electric locomotive suitable for operating on this system a specific operating situation involving CP Rail was investigated. The most restrictive segment of CP track, in regard to movement of goods westward, is between Rodgers and Stoney Creek on the Mountain Subdivision [9]. A tunnel is currently being constructed in order to reduce the ruling grade to 1.0% from a previous maximum of 2.2% on this segment. Electrification of the line has been considered and the tunnel has been constructed with clearances to accommodate a catenary. Operations, however, in the immediate future are planned based on the use of existing diesel-electric locomotives. One possibility envisions four C-C 3000 hp units pulling 80 cars for a total train weight of approximately 11,000 tons.

The performance of this train has been calculated with the results shown in Figure 7. The consist is shown at the top of the print-out together with locomotive, car, and route data. The total rail tractive effort of the four 3000 hp locomotives is shown as well as the coupler effort obtained by deducting the resistance of the locomotives themselves.

For the given grades the available locomotive coupler effort intersects with the trailing load resistance curve to give train balance speeds. These can be seen to be 56 mph on level, tangent track and 14 mph on the 1% grade. The latter speed is above the minimum continuous speed of the locomotives. Loss of one locomotive in the consist would put the locomotives into short-time overload but the grade could still be managed.

Figure 8 shows the effect of replacing the diesel-electric locomotives with an equal number of electrics of 6000 diesel-equivalent hp. The balance speed will now reach 28 mph and all units will be working at their continuous power rating. The consist is overpowered on level, tangent track since no balance speed is reached within the normal speed range.

The simulation was repeated using only three electric locomotives. Figure 9 shows that the balance speed will drop to approximately 23 mph in this case. Loss of one locomotive will stall the train although loss of a single motor or truck (3 motors) on one locomotive can be accommodated. There is little to be gained by increasing the installed power over that shown - the traction drive equipment is close to its current limits and the train can reach 70 mph on the level.

Finally, the simulation was repeated using the most modern diesel-electric locomotive available equipped for 3500 hp with improved traction drive and wheel-slip equipment. As can be seen from Figure 10 a consist of three such units has a slow-speed tractive effort capability comparable to that of the electrics discussed above. The balancing speeds are 13 and 52 mph for the 1% grade and level track respectively.

Comparing the performance for the various types and numbers of locomotives the following conclusions have been drawn:

- Three electrics or latest generation diesel-electrics can replace four older diesel-electrics in terms of continuous tractive effort in this application. There is a reduced reserve margin, however, in the event of a single locomotive failure.

```
****-1-XXXXXXXXXXXXXXXXX-2-****-3-XXXXXXXXXXXXXXXXXX-4-****
 4  Locos     80  Cars          0  Locos     0  Cars          0  Locos

          LOCOMOTIVE DATA                    CAR DATA
          ---------------                    --------
             weight : 195,0 s.tons          weight :131,5 s.tons
               area : 150,0 sq.ft.            area :100,0 sq.ft.
          no.axles :   6                 no.axles :  4
     traction power :  3000 HP              type : freight
     no.of  D.E. locomotives :  4        no of cars :  80

        ROUTE CHARACTERISTICS
        ---------------------
100% adhesion
Curvature of  0  degrees
Grades:
   GRADE #1        0  %
   GRADE #2        1  %

                                   ANALYSIS AT COUPLER NO. 1
```

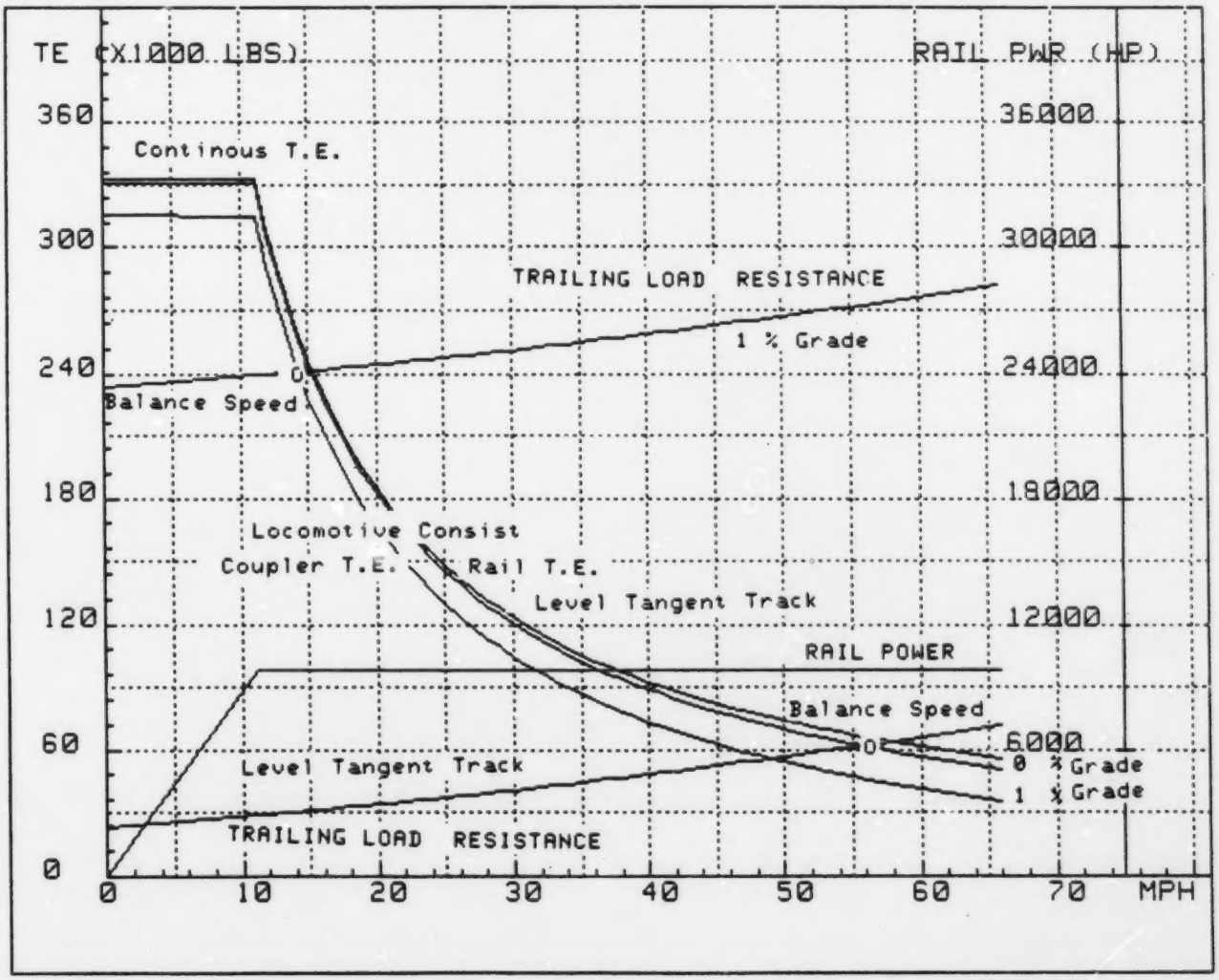


Figure 7. Simulation of CP Rodger's Pass Operation with 4 DE Locos

```
####-1-XXXXXXXXXXXXXXXXXX-2-####-3-XXXXXXXXXXXXXXXXXX-4-####
4  Locos     80  Cars          0  Locos     0  Cars          0  Locos
```

LOCOMOTIVE DATA		CAR DATA	
weight :	196,1 s.tons	weight :	131,5 s.tons
area :	150,0 sq.ft.	area :	100,0 sq.ft.
no.axles :	6	no.axles :	4
traction power :	5092 HP Rail	type :	freight
no.of ELEC locomotives :	4	no of cars :	80

ROUTE CHARACTERISTICS

100% adhesion
Curvature of 0 degrees
Grades:
GRADE #1 0 %
GRADE #2 1 %

ANALYSIS AT COUPLER NO. 1

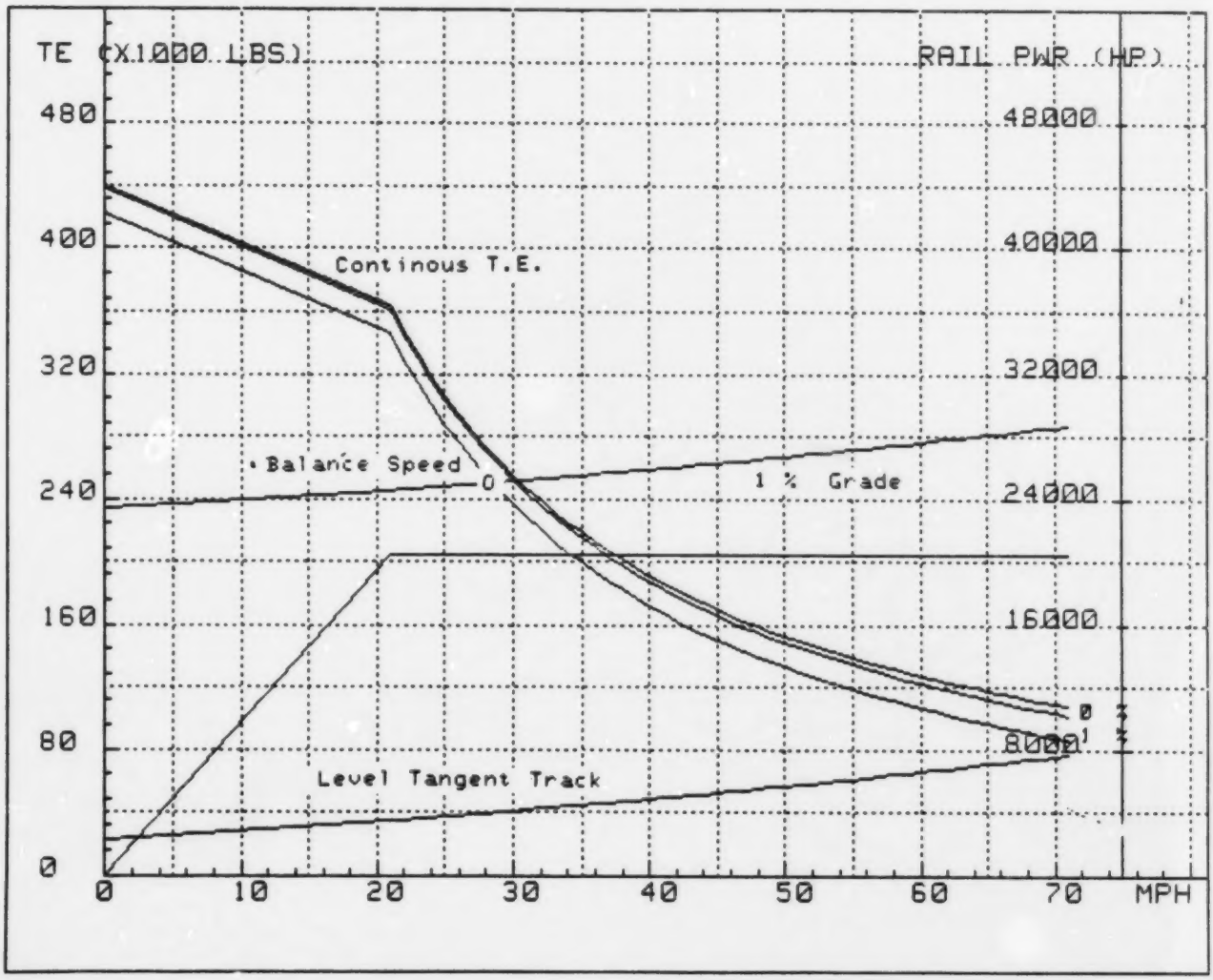


Figure 8. Simulation of CP Rodger's Pass Operation with 4 E Locos

```
####-1-XXXXXXXXXXXXXXXXX-2-####-3-XXXXXXXXXXXXXXXXX-4-####
3  Locos     80  Cars          0  Locos     0  Cars          0  Locos
```

LOCOMOTIVE DATA

```
weight : 196,1 s.tons
area : 150,0 sq.ft.
no.axles :  6
traction power :  5092 HP Rail
no.of ELEC locomotives :  3
```

CAR DATA

```
weight :131,5 s.tons
area :100,0 sq.ft.
no.axles :  4
type : freight
no of cars :  80
```

ROUTE CHARACTERISTICS

```
100% adhesion
Curvature of  0  degrees
Grades:
   GRADE #1        0  %
   GRADE #2        1  %
```

ANALYSIS AT COUPLER NO. 1

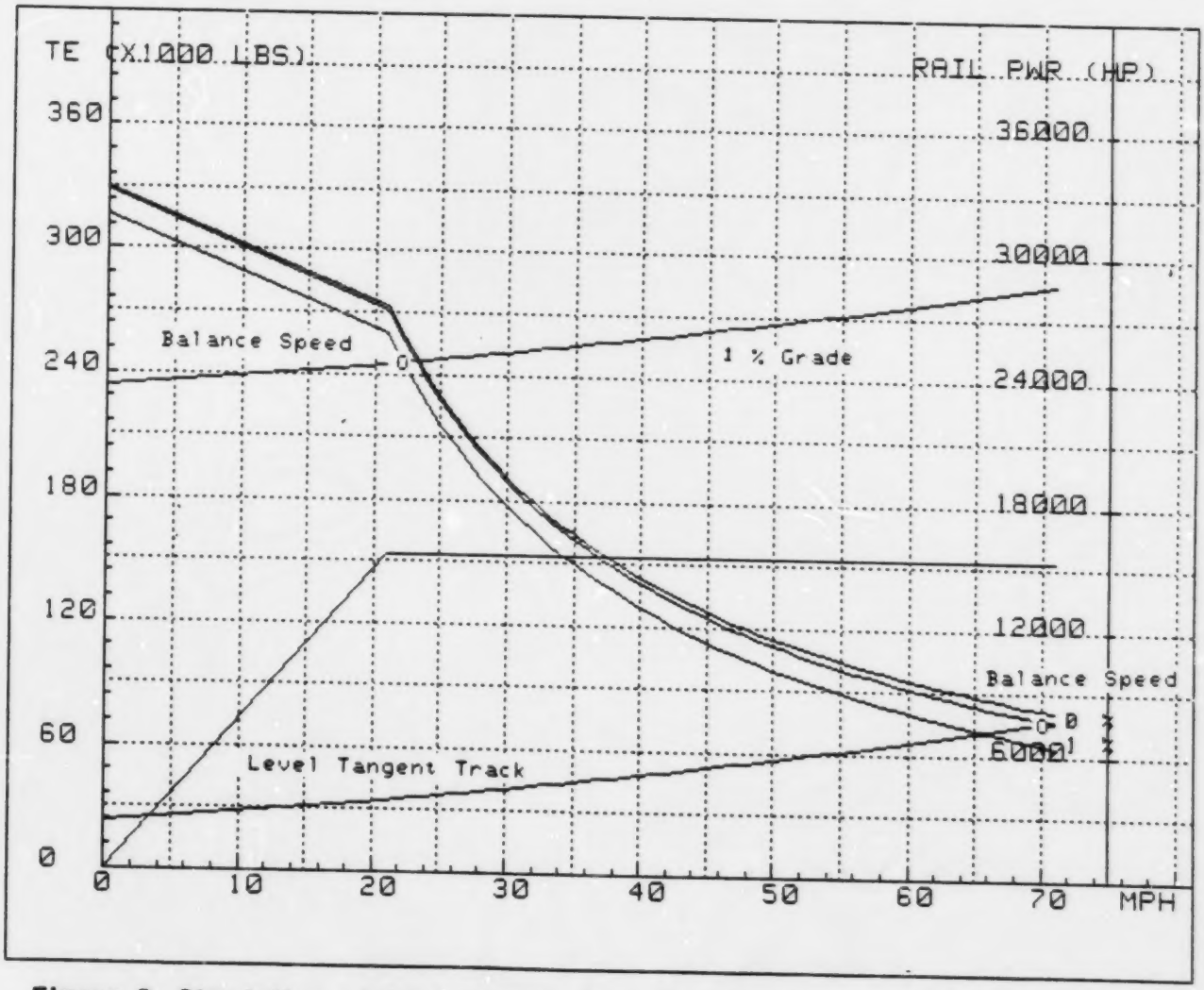


Figure 9. Simulation of CP Rodger's Pass Operation with 3 E Locos

```
####-1-XXXXXXXXXXXXXXXXX-2-####-3-XXXXXXXXXXXXXXXXX-4-####
3  Locos     80  Cars          0  Locos     0  Cars          0  Locos
```

LOCOMOTIVE DATA		CAR DATA	
weight	195,0 s.tons	weight	131,5 s.tons
area	150,0 sq.ft.	area	100,0 sq.ft.
no.axles	6	no.axles	4
traction power	3500 HP	type	freight
no.of D.E. locomotives	3	no of cars	80

ROUTE CHARACTERISTICS

100% adhesion
Curvature of 0 degrees
Grades:
GRADE #1 0 %
GRADE #2 1 %

ANALYSIS AT COUPLER NO. 1

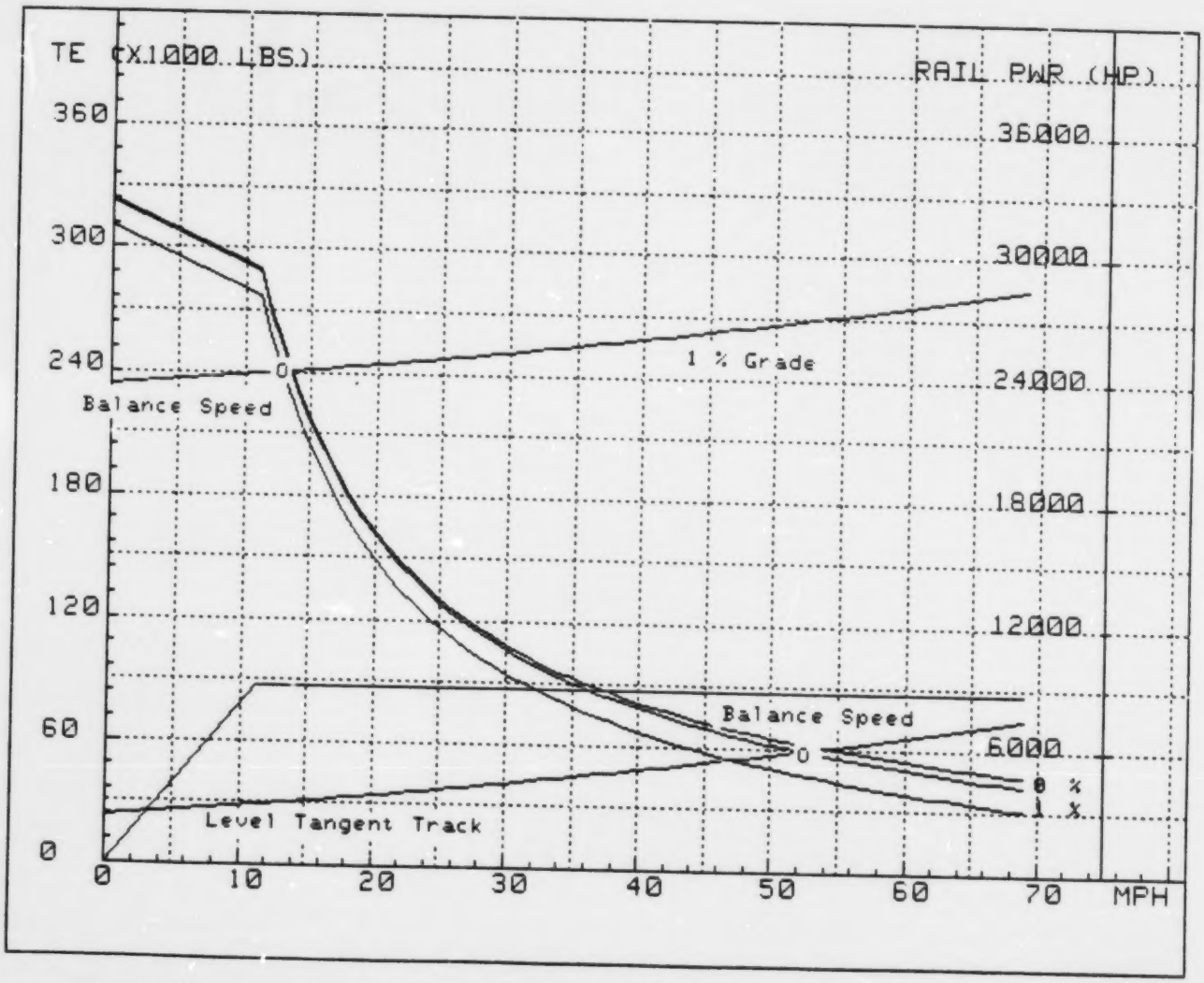


Figure 10. Simulation of CP Rodger's Pass Operation with 3 DE Locos

- Three electrics of 6000 diesel equivalent hp each will almost double the train speed on the grade compared to three 3500 hp diesel-electrics. In addition, sufficient power exists to accelerate the train quickly as well as operate at maximum line speed continuously on the level.

- more than 6000 hp installed continuous diesel equivalent power per electric locomotive would not provide any significant additional benefits.

- C-C units are required in order to provide sufficient adhesion weight on the grade.

2.3.3 Special Applications Involving 50 kV Locomotives in North America.

2.3.3.1 Deseret-Western Railway.

The Deseret-Western Railway is a unit-train, coal-hauling operation located in the Utah-Colorado area of the United States. It was completed in 1984 as a standard gauge, 38 mile long single track electrified railway at a nominal 50 kV 60 Hz AC and is completely separate from any other railroad [10].

The baseline performance requirement [11] was based on the following configuration:

- train load : 62 coal cars
- ruling grade : 1.8% in loaded direction
- locomotive consist: 4 electric locomotives
- locomotive weight : 216 tons max
  204 tons nominal
- locomotive type : C-C

The continuous tractive effort was specified to be 100,000 lbs for each locomotive. This level of tractive effort was to be mainained up to a speed of 20 mph with 50 kV available at the pantograph. The rail power for each locomotive reaches 5333 hp (3980 kW) at this speed, which corresponds to about 6500 diesel-equivalent hp.

Electric locomotives were purchased from G.E. based on the E60 used on the Northeast Corridor and Mexico. The locomotive physical characteristics are summarized in Table 1.

Manufacturer	GM, Can.	GE, USA
Model	GF6C	E60C
Gauge	4' 8-1/2"	4' 8-1/2"
Length (over couplers)	68' 10"	70'
Bolster-to-bolster distance	43' 6"	45' 0"
Wheel arrangement	C-C	C-C
Wheel diameter	42"	40"
Gear ratio	83:18	85:21

TABLE 1

50 kV Electric Locomotives used in North America

Figure 11 depicts the tractive effort at the coupler of the first car in a train of 62 cars pulled by a four-locomotive consist with 50 kV available at the pantograph. The train balancing speed on the 1.8% grade would be approximately 23 mph if sufficient voltage were available. In reality the grade is located 30 miles from the substation with the result that the voltage at the locomotives drops to a nominal 38 kV. The reported train speed in this case falls to about 14 mph, which corresponds to an individual locomotive rail power of somewhat less than 4000 hp. The reduced line voltage slows but does not stop operations since the tractive effort is maintained at a high level. This means, however, that the auxiliary system had to be designed to furnish adequate cooling of the equipment at 38 kV - the specified minimum voltage rating for continuous performance - which leads to a significant oversizing of the auxiliary power conversion equipment.

The locomotives are also characterized by a 30-minute rating of 30 kV. In the line voltage range of 30 to 38 kV the full tractive effort would be developed but equipment cooling would be insufficient. It can be expected in this case that, despite an anticipated balancing speed of only about 6 mph, the train would clear the grade in the allowable time interval.

```
####-1-XXXXXXXXXXXXXXXXX-2-####-3-XXXXXXXXXXXXXXXXX-4-####
4 Locos    62 Cars        0 Locos    0 Cars        0 Locos

CONVENTIONAL LOCO     CONVENTIONAL CAR     ANALYSIS AT COUPLER NO. 1

                  LOCOMOTIVE DATA                    CAR DATA

                     weight : 204,0 s.tons    weight :131,5 s.tons
                       area : 140,0 sq.ft.      area :100,0 sq.ft.
                  no.axles :   6           no.axles :  4
            traction power :  5333 HP          type : freight
            no.of E-60 locomotives :  4     no of cars :  62

                ROUTE CHARACTERISTICS

      100% adhesion
      Curvature of  0  degrees
      Grades:
         GRADE #1        0  %
         GRADE #2        1.8  %
```

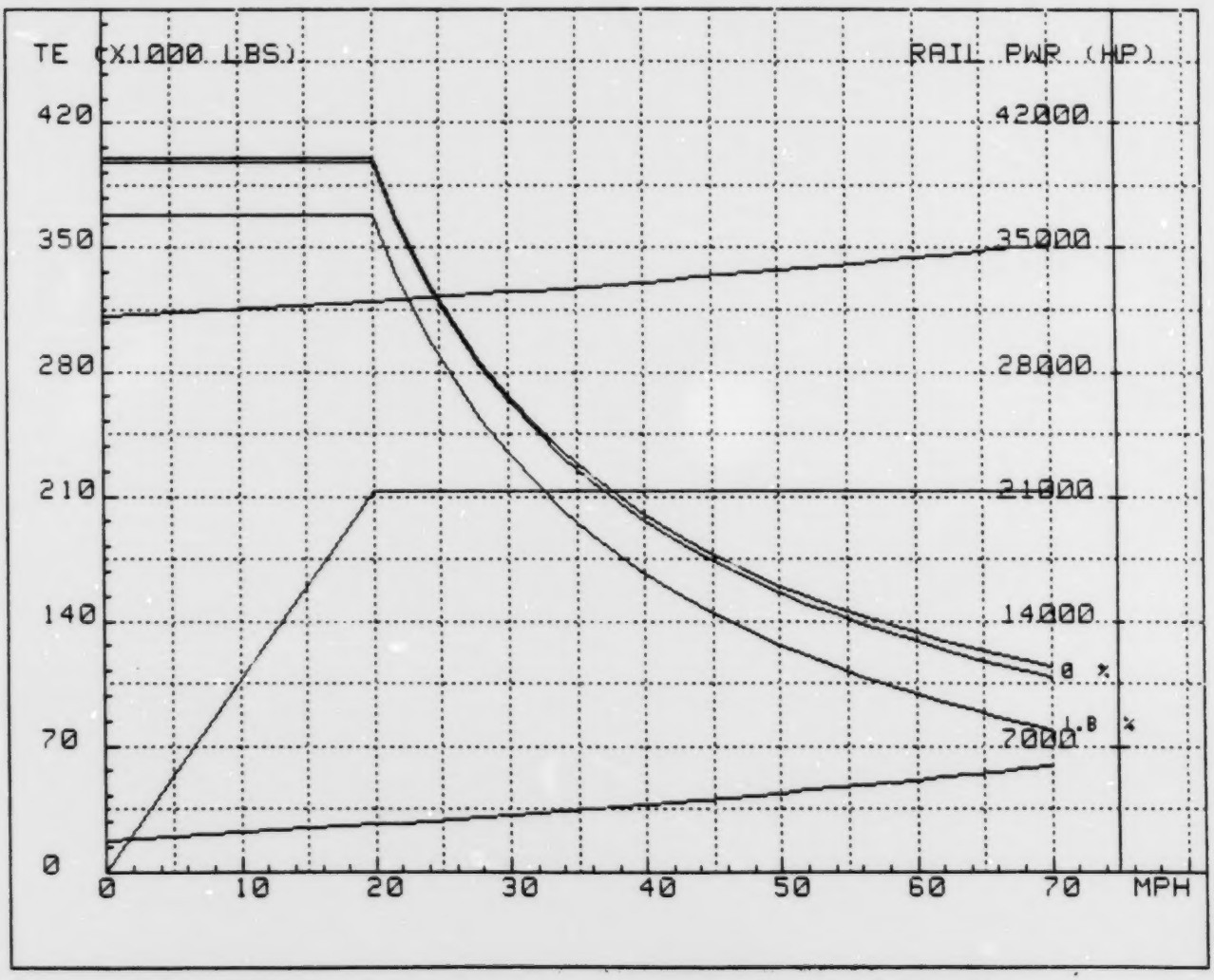


Figure 11, Simulation of Deseret-Western Operation with E Traction

2.3.3.2 Tumbler Ridge Division of B.C. Rail.

The Tumbler Ridge Operation of B.C. Rail uses a 129 km new branch line electrified at 50 kV to move coal in unit trains from mine sites to an interchange point at Anzac, B.C. The line is standard gauge, single track and passes through two main tunnels 9 and 11 km long. The justification for electrification was partially based on the savings resulting from avoiding forced ventilation of these tunnels.

An electrification study [12] was performed to generate the performance requirements for locomotives to be used in the Tumbler Ridge operation based on the following:

- train load	:	98 coal cars
- ruling grade	:	1.2% in loaded direction
- locomotive consist	:	4 electric locomotives
- locomotive weight	:	197.5 tons
- locomotive type	:	C-C

The continuous tractive effort at the coupler on the ruling grade was calculated to be 82,250 lbs for each locomotive. The minimum speed acceptable with this level of tractive effort was set at 15 mph giving a required continuous power at the coupler of only 3290 hp (2455 kW). Approximately 6% more tractive effort and power would be required to account for the grade and other resistances of the locomotive itself; i.e. the rail tractive effort of each locomotive could be approximately 87,000 lbs and the rail power 3500 hp.

Electric locomotives were purchased from G.M., Canada [13] built using a combination of an existing locomotive frame, modified cab layout, and new carbody design. Traction equipment, with the exception of the traction motors, were provided by ASEA, Sweden. Table 1 summarizes the locomotive physical characteristics.

The performance of the locomotive is superior to the minimum required for operation on the Tumbler Ridge Branch Line. This is reflected in the simulation results of Figure 12 which shows a balancing speed of approximately 19 mph on the 1.2% grade.

```
####-1-XXXXXXXXXXXXXXXXXX-2-####-3-XXXXXXXXXXXXXXXXXX-4-####
 4  Locos     98  Cars          0  Locos     0  Cars          0  Locos

CONVENTIONAL LOCO     CONVENTIONAL CAR     ANALYSIS AT COUPLER NO. 1

                  LOCOMOTIVE DATA                    CAR DATA

                     weight : 196,1 s.tons     weight :131,5 s.tons
                       area : 150,0 sq.ft.       area :100,0 sq.ft.
                  no.axles :   6             no.axles :  4
             traction power :  5092 HP           type : freight
             no.of GF6C locomotives :  4     no of cars :  98

                  ROUTE CHARACTERISTICS

100% adhesion
Curvature of  0  degrees
Grades:
   GRADE #1        0  %
   GRADE #2        1.2  %
```

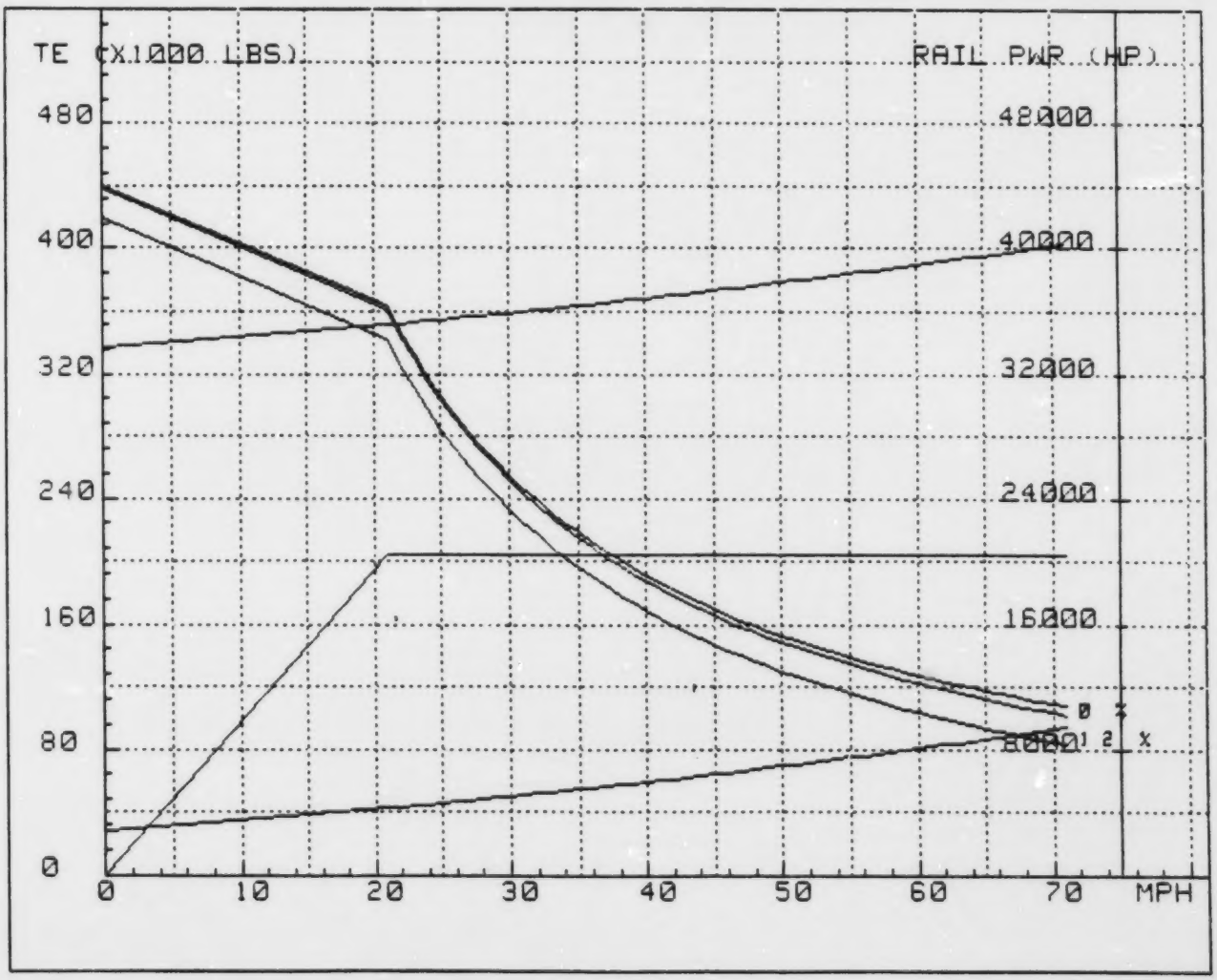


Figure 12. Simulation of Tumbler Ridge Operation with E Traction

In actual practice the train would not be configured with 4 locomotives at the head end because of coupler strength limitations. Presently two locomotives are used on the front end and two pushers used at the rear of the train (units which are then removed after the grade). Balancing speeds are reported to be in the 20-25 mph range because of the short-time overload capability of the locomotives, and, possibly, lower train resistance than assumed in the simulation since all the cars are of the steerable-axle, roller bearing design.

2.3.4 Power Requirements for 6-Axle Locomotives.

The three cases analyzed above are representative of heavy-haul railroading in moderately graded (up to 1.8% terrain. Suitable locomotives for these applications would have C-C wheel arrangements and installed power of approximately 6000 diesel-equivalent hp. Significantly higher installed power suggested in some reports [13] is not useful in the sense developed in section 2.3.1 as its utilization to reduce the number of locomotives in a consist would require uncommonly high levels of continuous adhesion utilization, marked deviation from existing North American wheel size and truck practices, and reduced ability to compensate for locomotive breakdowns.

It has been pointed out by at least one railroad [14] that the greatest financial incentive to electrify resides in the cost differential between diesel fuel and electric power. Operating a given train with higher power locomotives will reduce travel time but will increase energy costs and especially demand charges. The time saved may be of little value for bulk commodities and the power demand of locomotives would be limited by operator instructions and/or a remote power dispatcher. Locomotives with very large installed power capacity would, under these circumstances, be forced to operate almost always in a partial load condition and be, therefore, underutilized.

2.3.5 Power Requirements For 4-Axle Locomotives

In territory where all ruling grades are of the order of .7% or less 4-axle electric locomotives will be a more suitable choice. They will be operated in high-speed service where time and not flow is the critical variable. Relatively high hp-per-ton values [15] are required and electrics would be able to realize all the advantages described in section 2.3.1.

While the optimal installed power in 4-axle units will depend on the actual track profiles and operating considerations it will basically be constrained to fall within the following two extremes:

- Installed power equal to that installed in the 6-axle version. This would follow diesel-electric locomotive practice where the same power rating is offered in both configurations.

- Installed power proportional to axle count.

As will be discussed in a later section the electrical equipment and truck design may be strongly impacted by this decision. Since diesel-electric locomotives are operating already in the range of 3500-3600 hp on 4 axles little performance advantage and/or reduction in number of locomotives in a consist would be realized by adopting the lower power extreme (6000 diesel-equivalent hp x 4/6 = 4000 hp).

For this reason, design of a 4-axle locomotive will be based on an installed power in the 5000-6000 diesel equivalent hp range.

2.4 Electric Braking.

A train will have three braking systems available:

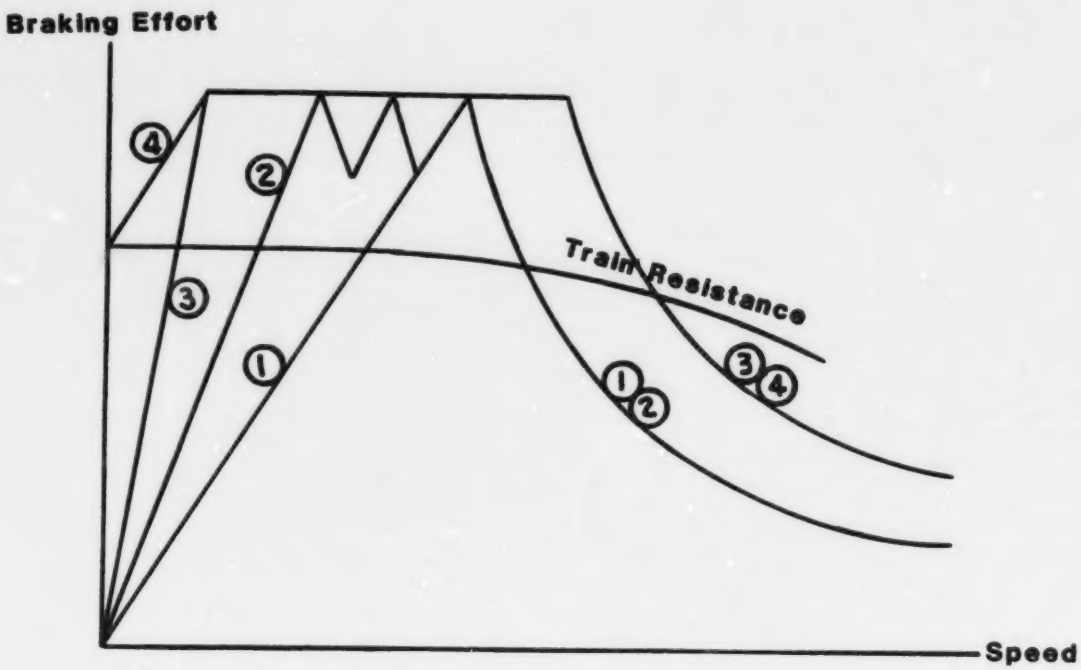
- train pneumatic brake.

- locomotive (independent) pneumatic brake.

- locomotive electric brake.

Braking a train on a grade is usually handled by a train pneumatic brake application to set a basic braking level together with use of the electric brake to control train speed as the terrain varies. The independent brake is cut out when the electric brake is operative.

It is desirable from the viewpoint of wheel and brake shoe wear and train controllability to do as much braking as possible electrically. Figure 13 depicts a number of conceptual braking effort versus speed curves for electric and diesel-electric locomotives.



① DE Locomotive

② DE Locomotive with Extended Range

③ E Locomotive

④ E Locomotive with Enhanced Low Speed Characteristics

Figure 13. Electric Braking Effort Characteristics

Since some of the same electrical equipment is used in electric braking as in motoring the maximum power-handling capability in electric braking would be equal or somewhat greater than the continuous motoring power rating. Electric locomotives, therefore, (Curves 3 and 4) can allow safe grade descent at higher speeds than diesel-electric units (Curves 1 and 2).

At lower speeds the electric braking effort is limited in order to avoid adhesion utilization demands in excess of 15-16%. At still lower speeds the electric braking effort will be reduced along various curves depending on the characteristics of the electrical equipment. The basic diesel-electric characteristic (Curve 1) can be extended by the addition of supplemental contactors (Curve 2). Electric locomotives, by virtue of their on-board controllers, can maintain braking effort down to much lower speeds (Curves 3 and 4) than conventional diesel-electric locomotives, although Curve 4 is also characteristic, at low speeds, for the braking performance of 3-phase AC diesel-electric locomotives.

An analogous situation exists for electric locomotive braking in regard to braking force and power as was the case for electric locomotive motoring. On steep grades electric locomotives must be added from traction adhesion considerations and are consequently greatly under-utilized in terms of electric braking power.

The number of locomotives, N, required to hold the speed of a descending train constant can be calculated [16] from:

$$N = W_w / (F / s - W_l)$$

whereby:
- W_w = trailing load (tons).
- W_l = individual locomotive weight (tons).
- F = available braking force per locomotive at desired speed (tons).
- s = grade expressed as decimal.

As an example, for a 6000 ton trailing load descending a 1% grade with 60,000 lbs retarding force from each 180 ton locomotive the train can be safely held by:

$$N = \frac{6{,}000}{30/.01 - 180} = 2.13 = 3 \text{ locomotives}$$

This assumes, for simplicity, no resistance components are acting (aerodynamic drag, rolling resistance) to slow the train. If the speed limit on the grade is 30 mph the required rail power per locomotive will be approximately 4800 hp.

Diesel-electric locomotives are restricted to dynamic braking only, whereby the energy from the traction motors operating as generators (or alternators) is transformed into heat in braking resistor grids. Electric locomotives may be supplied with dynamic brake, regenerative brake or a combination of both. Regenerative braking involves transformation of the train's braking energy into electrical energy of a form suitable for injection into the electrification system. It is most effective where consumer density is sufficiently great that the probability of a recipient of the energy being available at the time of braking approaches unity. Usually the equipment will be configured such that dynamic brake is available if the line is non-receptive; i.e. if the system voltage becomes excessive when injection of the braking energy is attempted. The braking effort curve of the electric locomotive is usually independent of whether dynamic or regenerative braking is operating at a particular moment.

Given the low population density over much of the route, expected long distances between substations and relatively infrequent but powerful trains projected for Canadian electrification, regeneration does not appear cost-effective.

As indicated above, very high power dissipation brake resistors can be installed into electric locomotives. Realizing, however, that speed limits in steeply graded territory are usually kept quite low for a number of reasons (possibility of DB failure, sharp curves, etc.) the DB resistors, in reality, may not have to handle more than the equivalent of 5000 rail hp in a 6-axle electric locomotive and 4000 rail hp for a 4-axle unit. At 60,000 and 40,000 lbs maximum braking effort, the minimum speeds for full utilization of the braking power will be 31 and 37.5 mph for 6 and 4 axle locomotives respectively.

3. LOCOMOTIVE FEASIBILITY LAYOUTS

3.1 Locomotive Configurations

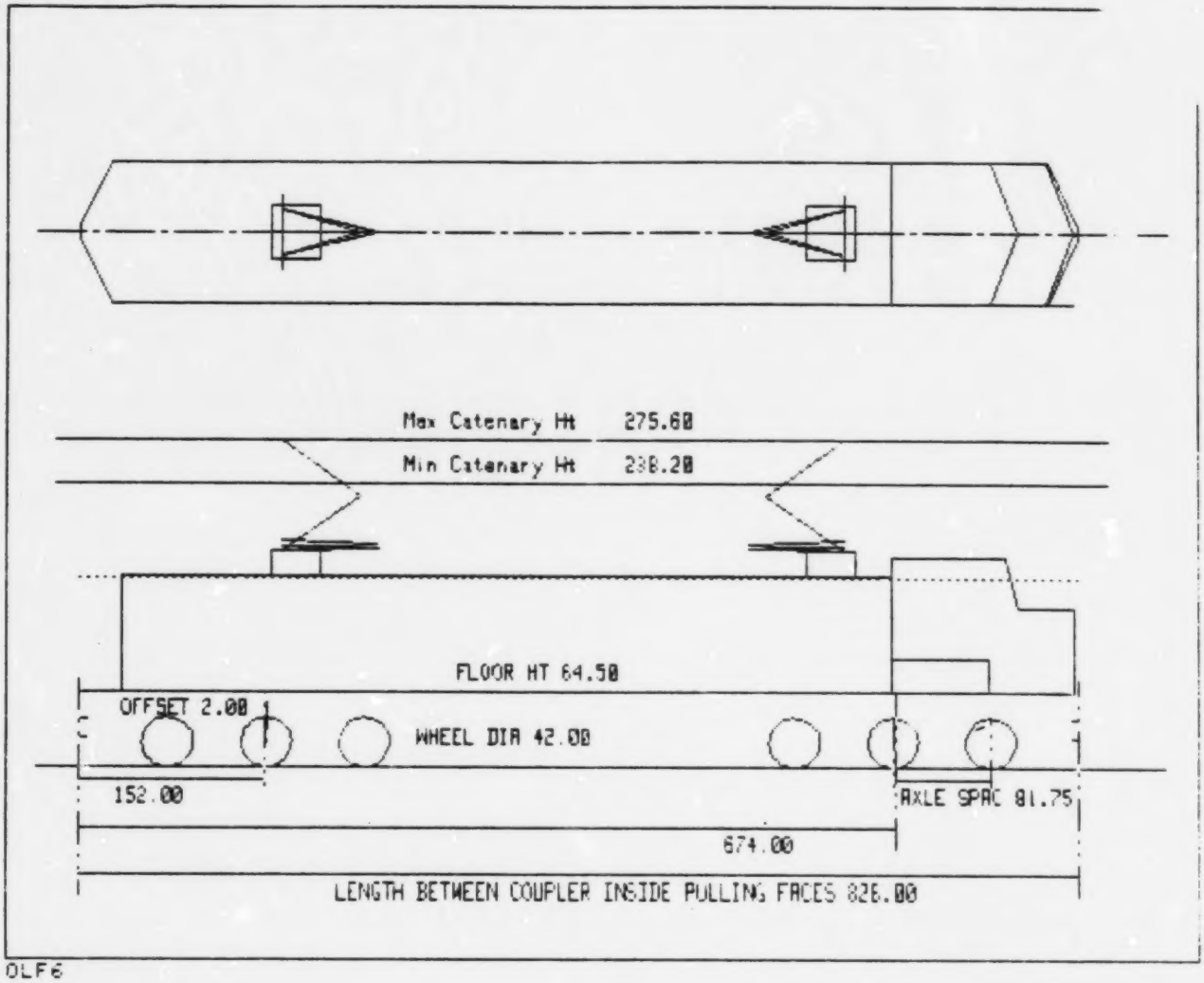
In order to cover the entire North American market a number of locomotive designs will be required. These will not only differ in the performance requirements but also in axle (B-B versus C-C), cab, and body configurations. The most probable alternatives are presented in Table 2 below:

	Axle Configuration	Body Type	Cab Type/No.
1.	C-C	Full width carbody	"CN" 1
2.	C-C	Tapered carbody	"CN" 1
3.	C-C	Full width carbody	"Euro" 1
4.	C-C	Full width carbody	"Euro" 2
5.	C-C	Narrow hood	"CN" 1
6.	B-B	Full width carbody	"Euro" 1
7.	B-B	Full width carbody	"Euro" 2
8.	B-B	Narrow hood	"CN" 1
9.	B-B	Full width carbody	"CN" 1

ELECTRIC LOCOMOTIVE CONFIGURATIONS

TABLE 2

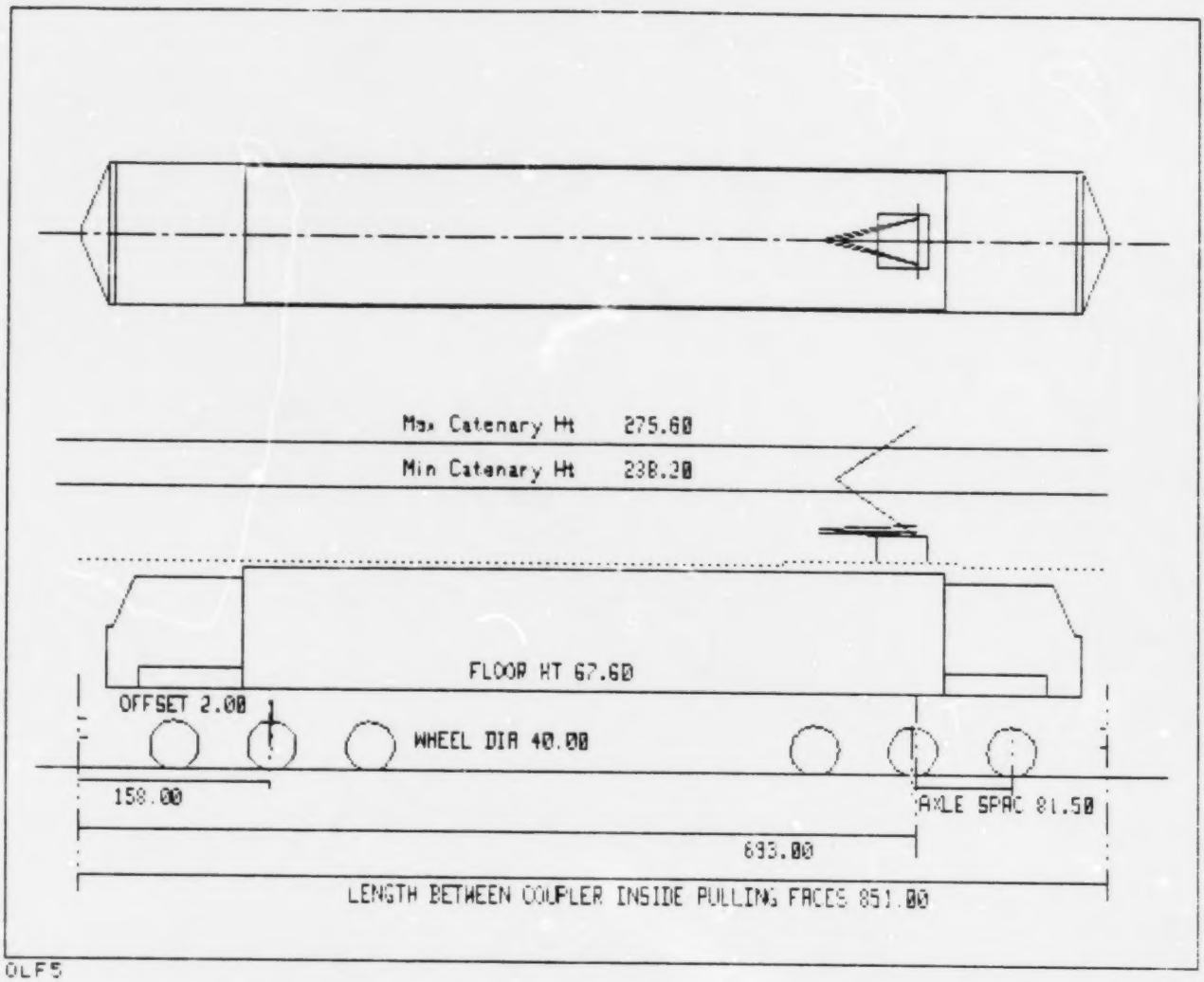
The "CN" cab (Figure 14) is characterized by a full-width section of short hood ahead of the cab area. The short hood is lacking on the "Euro" version (Figure 15). The "Euro" cab is usually placed at the extreme end of the frame and typically does not have an entry door provided in the front. The "CN" cab will have a door in front leading into the short hood and consequently through an interior door into the crew area. The short hood usually contains the locomotive toilet and miscellaneous equipment. In a wide-body locomotive the toilet may be relocated and the short hood reduced in length. The short hood may be placed at the extreme end of the frame or a platform and steps provided for switching purposes.



OLF6

LOCO LENGTH	L1	826.00
START OF FRAME	Fo	25.00
TRUCK NO 1 CONN	T1	152.00
TRUCK NO 2 CONN	T2	674.00
WHEEL DIAMETER	Wd	42.00
FLOOR HEIGHT	Hf	64.50
FRAME WIDTH	Wf	120.00
NO OF LOCO AXLES	Na	6.00
AXLE OFFSET FROM TRUCK CONN	Os	2.00
AXLE SPACING	As	81.75

Figure 14. CN Cab, Carbody - Type,C-C Electric Locomotive Configuration



LOCO LENGTH	L1	851
START OF FRAME	Fo	22.5
TRUCK NO 1 CONN	T1	158
TRUCK NO 2 CONN	T2	693
WHEEL DIAMETER	Wd	40
FLOOR HEIGHT	Hf	67.6
FRAME WIDTH	Wf	119
NO OF LOCO AXLES	Na	6
AXLE OFFSET FROM TRUCK CONN	Os	2
AXLE SPACING	As	81.5

Figure 15. Dual Euro Cab, Carbody - Type, C - C Electric Locomotive Configuration

The full width carbody with a single cab offers a maximum of equipment installation space. Visibility to the rear is virtually non-existent unless a tapered section is provided behind the cab. The CN HR616 diesel-electric locomotive is of this configuration. Alternately, a cab may be provided on both ends of the locomotive. These should be "Euro" type cabs in this case since "CN" cabs are longer and would inordinately reduce equipment installation space (Figure 16).

The single cab full-width carbody locomotive without taper is appropriate for semi-permanent coupling to another similar unit facing in the opposite direction. This is the manner of operating on the BC Rail Tumbler Ridge Division.

3.2 System Voltage, Catenary Height, and Roof Configuration

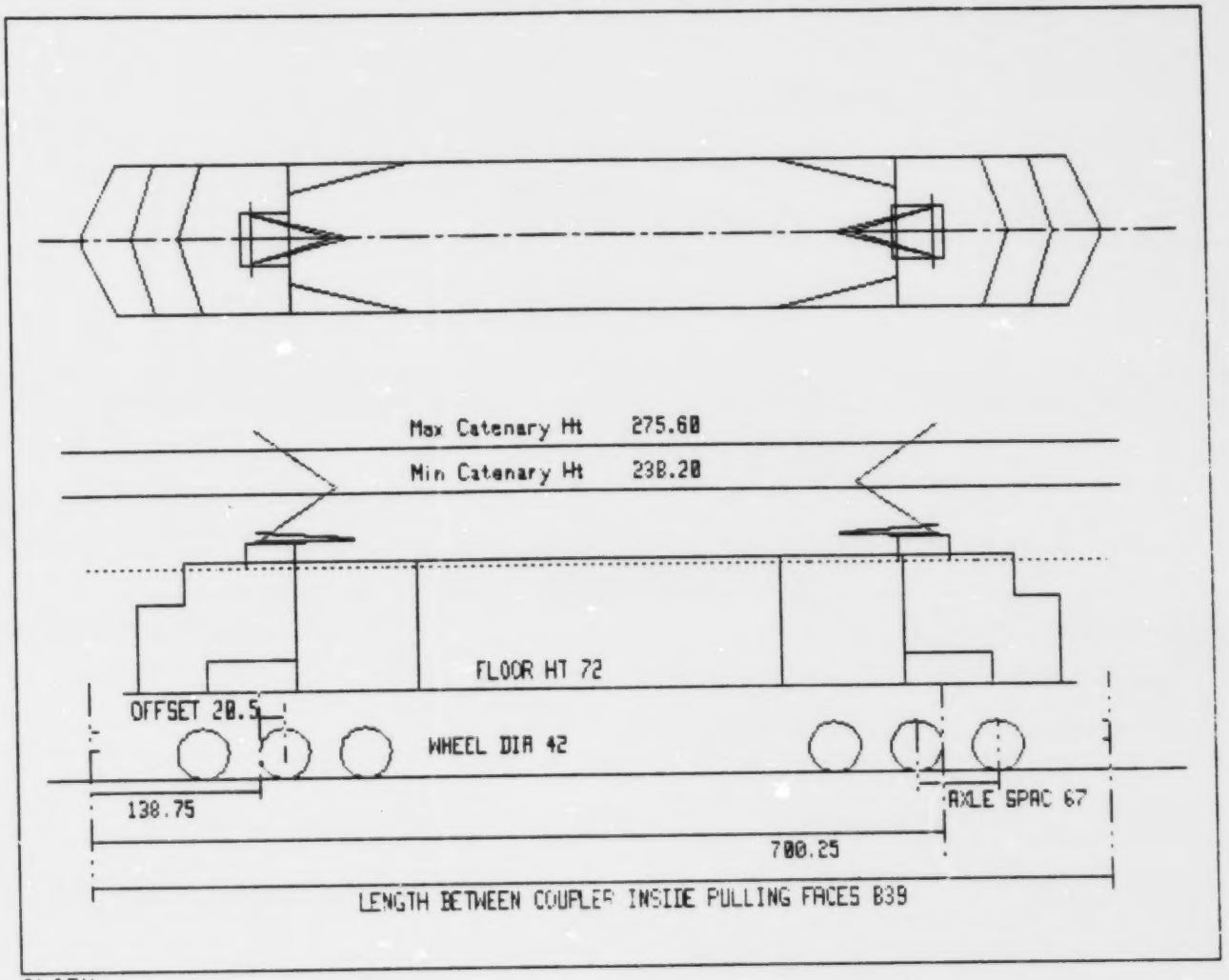
The entire locomotive design is impacted by the catenary height and choice of system voltage. The logical point to investigate these relationships is at the pantograph.

A pantograph is characterized by three positions:

- lock-down
- minimum extension
- maximum extension

In the lock-down position sufficient clearance must be available to prevent flashover from the catenary. The catenary height will vary around its nominal value because of local constraints and environmental conditions. The pantograph must be selected to accomodate the minimum and maximum catenary height within its rated extension limits.

According to AREA, at 50 KV nominal catenary voltage an electrical clearance of at least 530 mm (21 in) is required between the lowest specified catenary height and the highest projected point on the train. The latter reflects the load gauge plus possible future track uplift [17]. AREA's standard for the 50 kV nominal contact wire height is 7255 mm (285.6 in) which is sufficiently generous to allow operation of "high cube" plate F cars with a loading gauge of 5207 mm (205 in).



OL0FX

LOCO LENGTH	L1	839
START OF FRAME	Fo	27
TRUCK NO 1 CONN	T1	138.75
TRUCK NO 2 CONN	T2	700.25
WHEEL DIAMETER	Wd	42
FLOOR HEIGHT	Hf	72
FRAME WIDTH	Wf	125
NO OF LOCO AXLES	Na	6
AXLE OFFSET FROM TRUCK CONN	Os	20.5
AXLE SPACING	As	67

Figure 16. Dual CN Cab, Tapered Carbody, Type C - C Electric Locomotive Configuration

An electric locomotive designed to the same 4591 mm (181 in) cab height as the existing CN diesel-electrics could be used under this catenary without concern. The locked-down pantograph and other roof-mounted equipment would be allowed to project some distance above the overall height figure quoted above.

The situation is somewhat different on the BC Rail Tumbler Ridge electrified line. There the catenary nominal height is 6502 mm (256 in) above top-of-rail. The minimum catenary height of 6000 mm (236 in) is reached in tunnels and on one bridge [18]. The required static passing clearance increases because of altitude to a value of 54 mm (21.4 in). The standard CN locomotive height could, however, still be used and, if a Ringsdorf type 29200A pantograph were placed to give a locked-down height of 5020 mm (197 in), the locked-down pantograph would have a minimum clearance of 980 mm (38.6 in) to the catenary and still be 406 mm (16 in) above the cab, the highest grounded point on the locomotive.

It was found, however, in carrying out simulations for the Tumber Ridge application that this pantograph locked-down height would unfavourably restrict internal equipment height over a large part of the locomotive length. The roof height must be depressed, in this case, to accomodate the insulators supporting the roof equipment as can be seen in Figure 14. It became necessary to raise the pantograph lockdown position to 5194 mm (204.5 in) in order to realize a roof height of 4293 (169 in) in the depressed area. The locked-down pantograph clearance is now 800 mm (31.5 in) which is still in excess of the minimum acceptable value of 544 mm(21.4 in). The dotted lines in Figures 14, 15, 16, portray the height limit for locomotive structures supporting high voltage equipment.

3.3 Cab and Pantograph Trade-off

With the pantograph placed in the preferred position over the effective truck pivot, the computer feasiblity layout simulation revealed an interference between the "CN" cab and pantograph. An outward-facing knuckle would lower the entire cab to the depressed area level; i.e. 4293 mm (169 in) in the above example, while normal cab height is 4591 mm (181 in).

An inward-facing knuckle creates a local height reduction only at the rear of the cab, as can be seen from the dotted line under the pantograph insulators in Figure 16. This can be avoided by moving the cab forward on C-C locomotives by either eliminating the platform and retaining the short hood or reducing the length of the short hood and keeping the platform.

A B-B locomotive cannot be compensated in this manner and will consequently be outfitted with reduced height cabs. Such locomotives would be equipped with forward-facing knuckles in order to provide more room for electrical equipment on the roof.

Cabs, on which part or all of the pantograph assembly rests, must be solidly constructed. This will require reinforcing of the cab roof which further reduces available internal height. This can be compensated by lowering the floor but a somewhat reduced operator eye height will result. The lowered floor changes the space available for equipment under the cab. Neither the visibility nor under-cab space reduction were found to present significant problems.

3.4 Equipment Installation

3.4.1 General

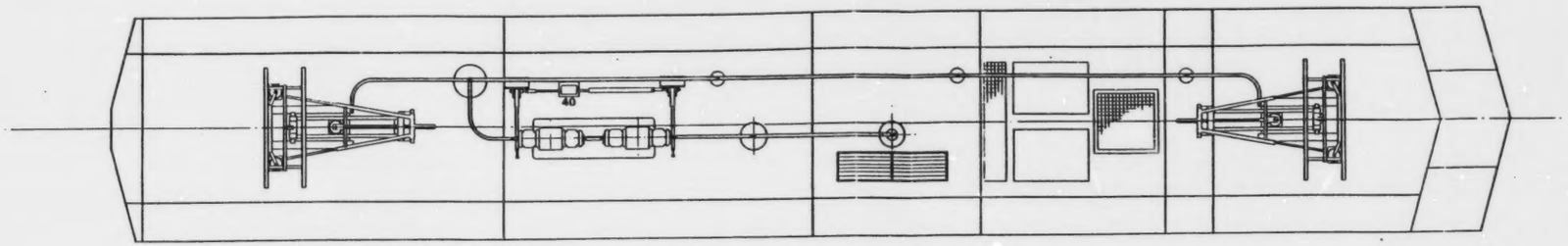
The two main areas of equipment installation study were in the body of the locomotive and on the roof. Following initial computer simulations of pantograph cab, and roof interactions, drafting board layouts were used to study overall equipment installation in order to determine layout feasibility.

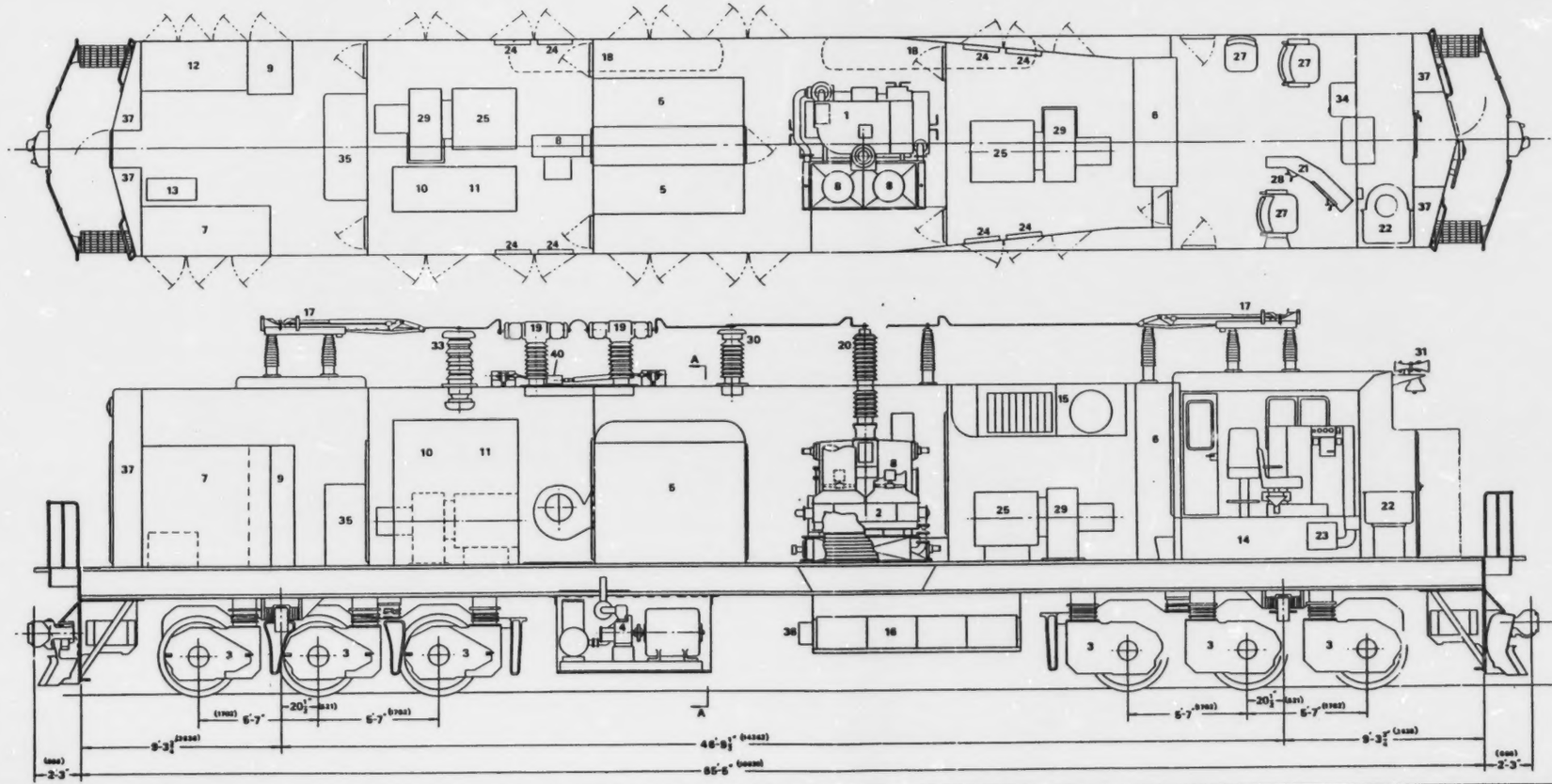
3.4.2 C-C Locomotive, Single Cab, Wide Hood

Figures 17a, b show one of the initial feasibility layouts developed. This C-C unit has a single lowered "CN"-type cab and a tapered carbody. The electrical equipment is of the air-cooled design as proposed by GEC to be similar to that used on the 50 kv ISCOR line in South Africa [19].

The heavy main components are transformer assembly (1), converters (5), and electrical cabinets (10, 11). They are installed in the middle part of the locomotive along its centerline. The locomotive batteries and air compressor are packaged underneath the locomotive.

In the locomotive body four distinct air-handling areas are separated by bulkheads and doors. In the two areas containing the blowers (29) air is taken in through carbody filters and blown into two sections of the frame. Frame air is ducted to the traction motors in each truck as well as to auxiliary equipment (11). The converters (5) are cooled by a separate blower, while the transformer is cooled by fans (8) circulating air through its oil-to-air heat exchangers (2).





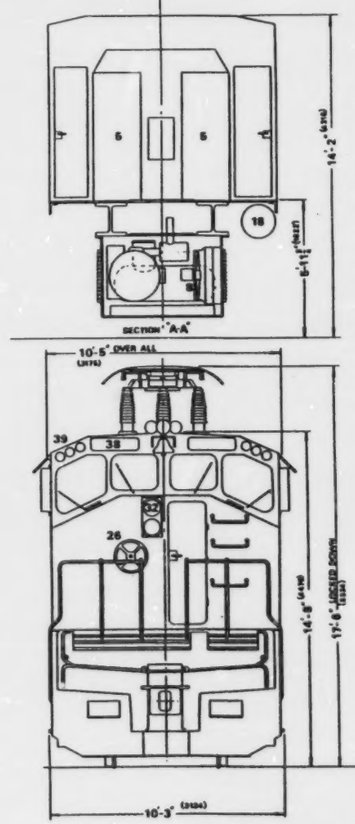
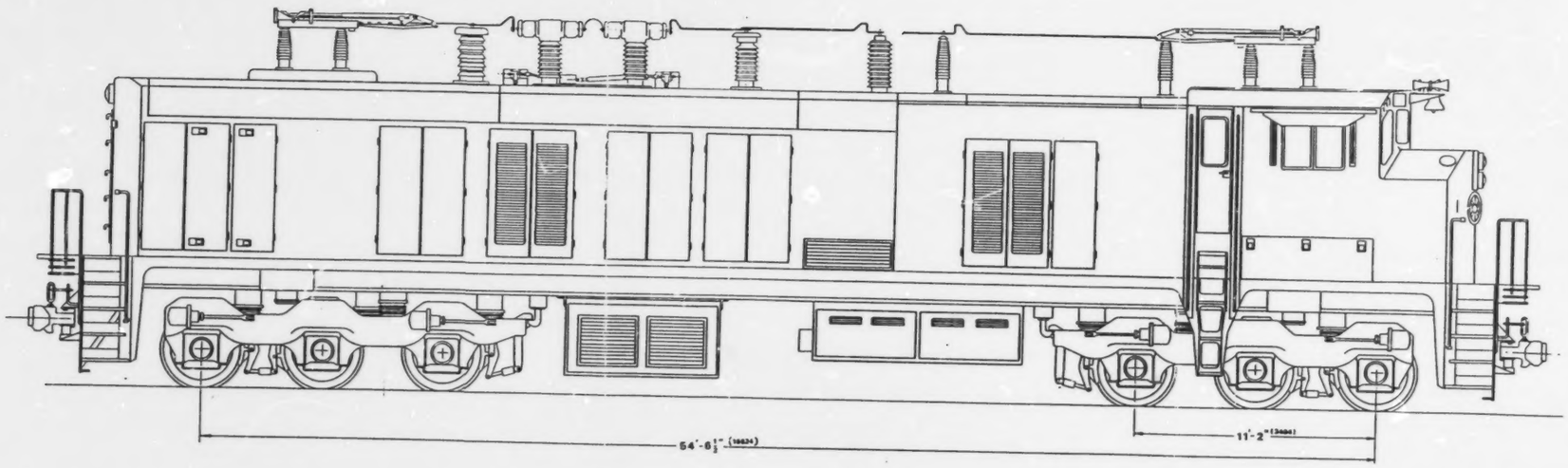


Figure 17a.



REF. A58-035020

Figure 17b.

In order to have access to both sides of the electrical cabinets (7, 9, 12) these were placed at the sides of the locomotive. The air compressor (4) is packaged for underframe mounting.

The roof-mounted equipment layout is straight-forward on this locomotive. Consideration had not yet been given at this point to roof section removal. Inward-pointing knuckles are shown although they could point in either direction on this unit. There would be no equipment installation problem in a C-C locomotive of the length shown.

3.4.3 C-C Locomotive, Double Cab, Wide Hood.

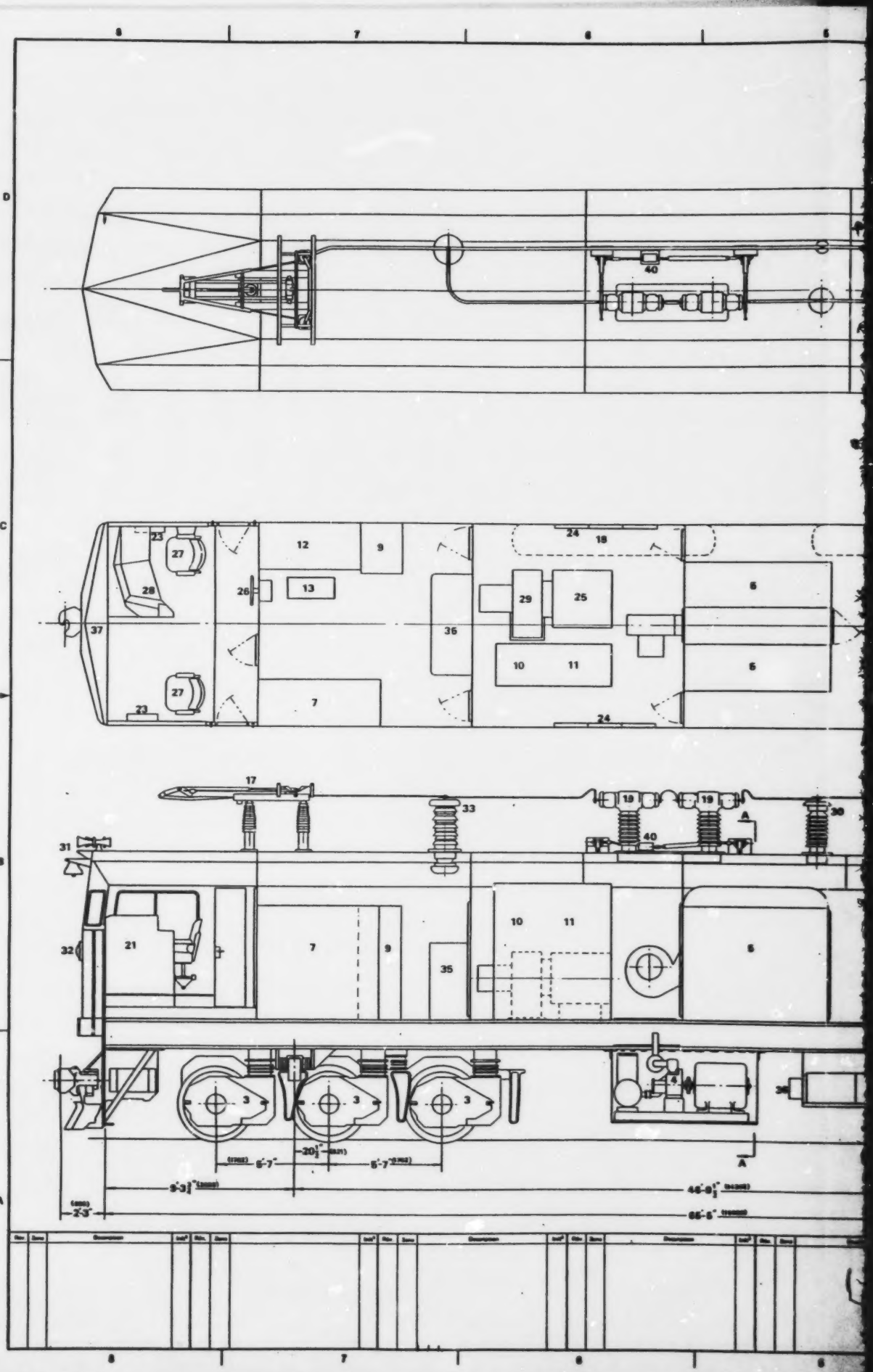
The feasibility of a double cab, carbody-type C-C locomotive was next investigated. Figures 18a,b show that the installation situation is similar to that discussed above if two "Euro" cabs are placed at the extreme ends of the locomotive. The equipment has moved forward to make space for the second cab, which has been lowered slightly to give a uniform roof line. This necessitates removal of the brake rack (14) to another location. Outward-pointing knuckles for the pantographs are used in this configuration.

3.4.4 C-C Locomotive, Single Cab, Narrow Hood.

The equipment complement can also be accomodated in a C-C narrow hood locomotive as can be seen from Figures 19a, b. In this case inertial air filters are used instead of panel filters. No major changes are required on the roof or under the frame. Sheeting has been added over the cab exits to offer improved protection to the crew from the 50 kV overhead. Entries are provided at the rear of the locomotive in order to gain access to the rear of some of the equipment cabinets. No feasibility problem was seen to exist with equipment installation in this configuration.

3.4.5 B-B Locomotive, Double Cab, Wide Hood.

Layouts for B-B locomotive equipment installation feasibility were carried out based on the same equipment complement as on the C-C locomotives discussed above. Traction motor limitations may preclude use of all the available power but little equipment size reduction could be realized by switching to a lower-rated transformer and converter.


8
7
6
5
D
C
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37
36
10
11
7
24
17
33
19
19
A
30
31
40
32
21
7
9
35
10
11
6
3
3
3
4
34
A
5'-7"
5'-7"
9'-3½"
44'-0½"
2'-3"
65'-6"

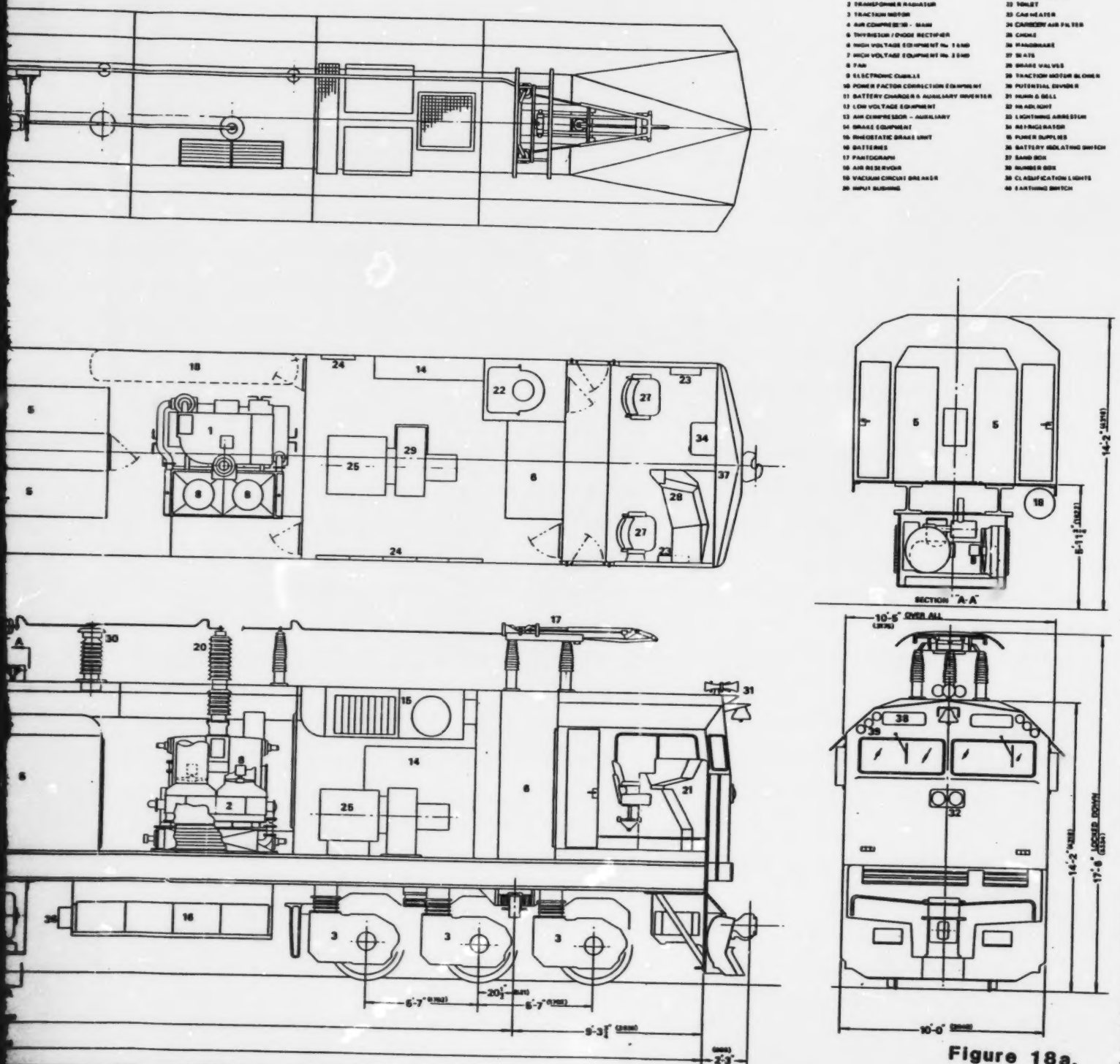
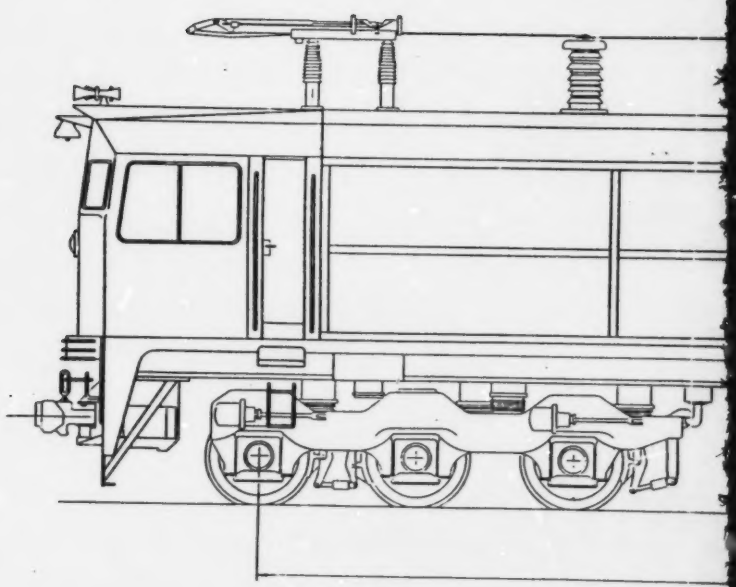


Figure 18a.

R.D.		Bombardier Inc. Bombardier Inc. Bombardier Produits ferroviaires et diesel Rail and Diesel Products Division Montréal, Québec, Canada		
PROJECTION		GENERAL ARRG'T.		
	AO	ELECTRIC LOCOMOTIVE TWO 'E' CABS W 'SE' HOOD		
		1/1	A98-095050-000	-



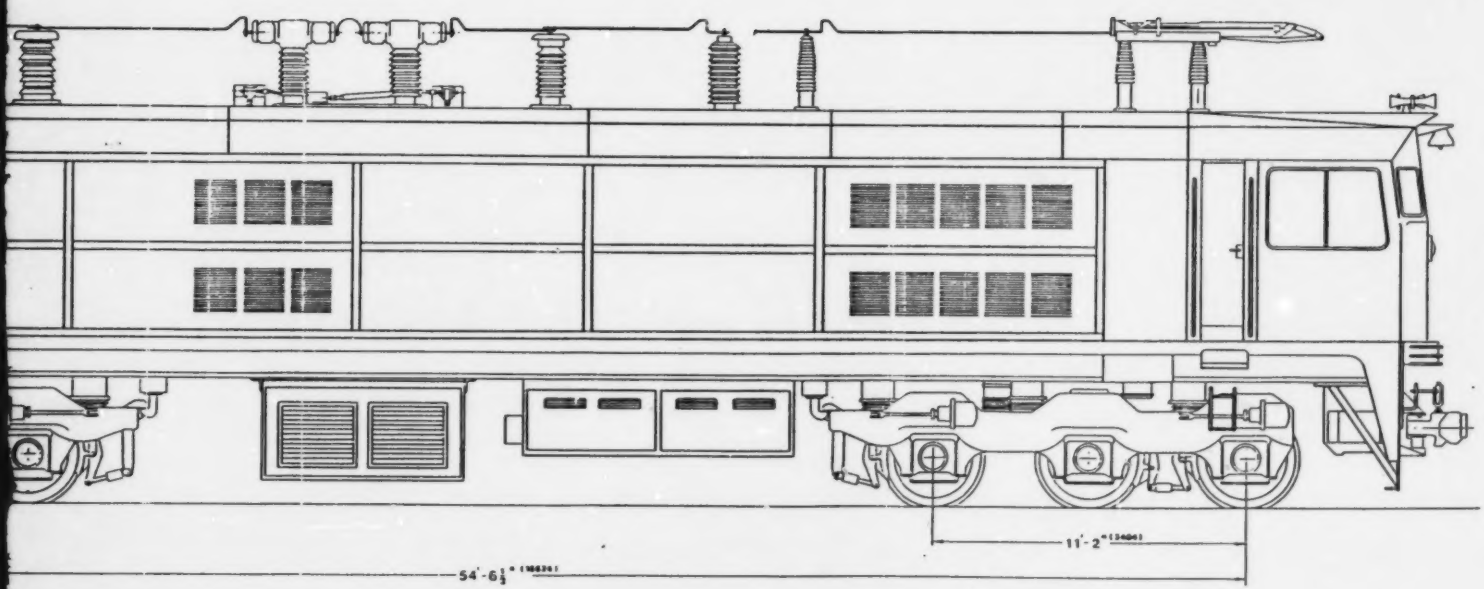


Figure 18b.

From Figures 20a, b, it can be seen that a configuration can be realized for installation of all the equipment required. The right-hand passageway is completely unimpeded - a desirable feature in regard to crew safety. The number of different air-handling areas has been reduced to three.

The roof arrangement has been altered to include separating switches for pantograph isolation - a feature desired by some operators. A different type of pantograph has also been adopted, the knuckle of which must now point outwards in order to leave sufficient space for the other roof-mounted equipment.

3.4.6 B-B Locomotive, Single Cab, Narrow Hood.

By tightening the space in the "CN"-type cab and in the rear of the body a B-B version of the narrow hood C-C locomotive can be realized with the same internal equipment (Figures 21a, b).

3.5 Feasible Configuration

Of the 9 possible alternative configurations presented in section 3.1 a total of 5 were drafted using the air-cooled GEC equipment as used in a 50 kV South African locomotive. Since these included the most difficult installation scenarios it was concluded that all the possible alternative configurations would be feasible at the level of detail considered.

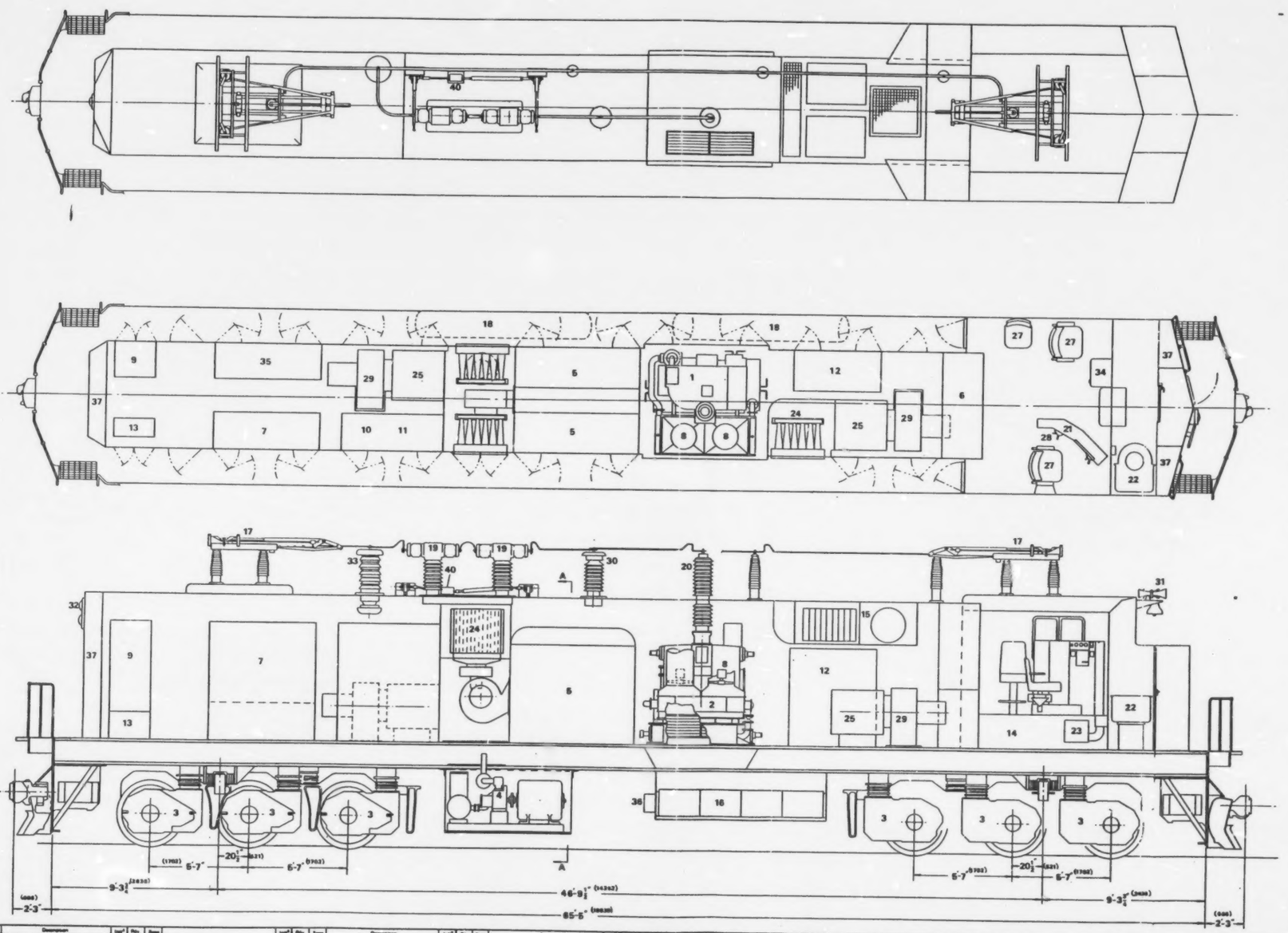


Figure 19a.

Bombardier Inc.	Bombardier Inc. Divisions des produits ferroviaires et diesel Rail and Diesel Products Division Montreal Québec, Canada
R.D. du 13 oct. 84	GENERAL ARRG'T. ELECTRIC LOCOMOTIVE SINGLE CAB NARROW HOOD
	A98-095010-000

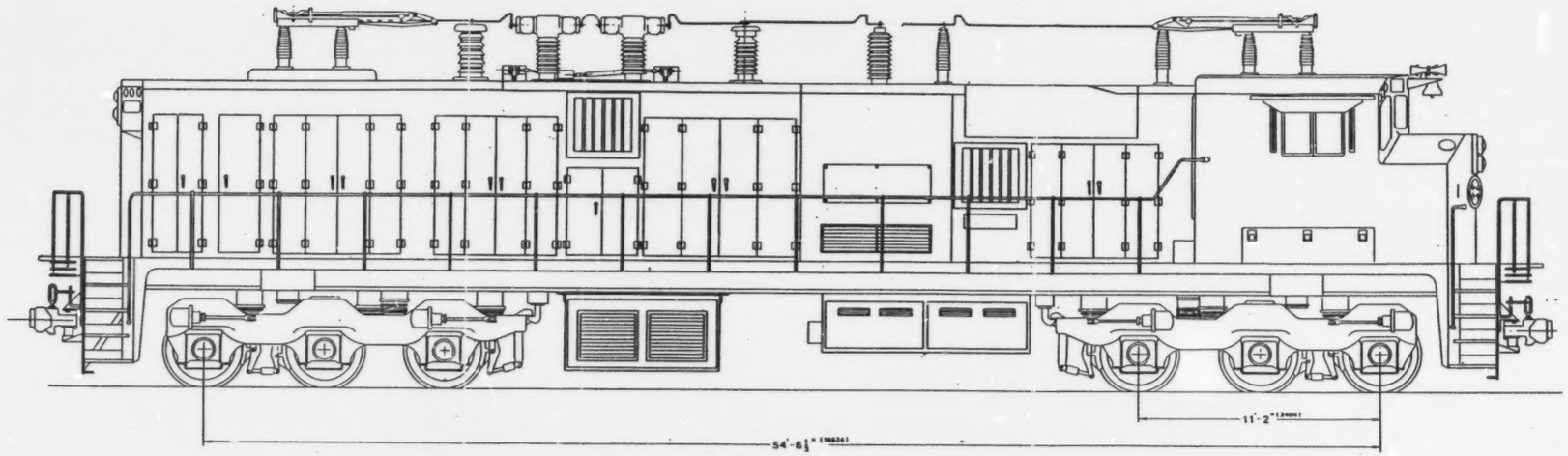


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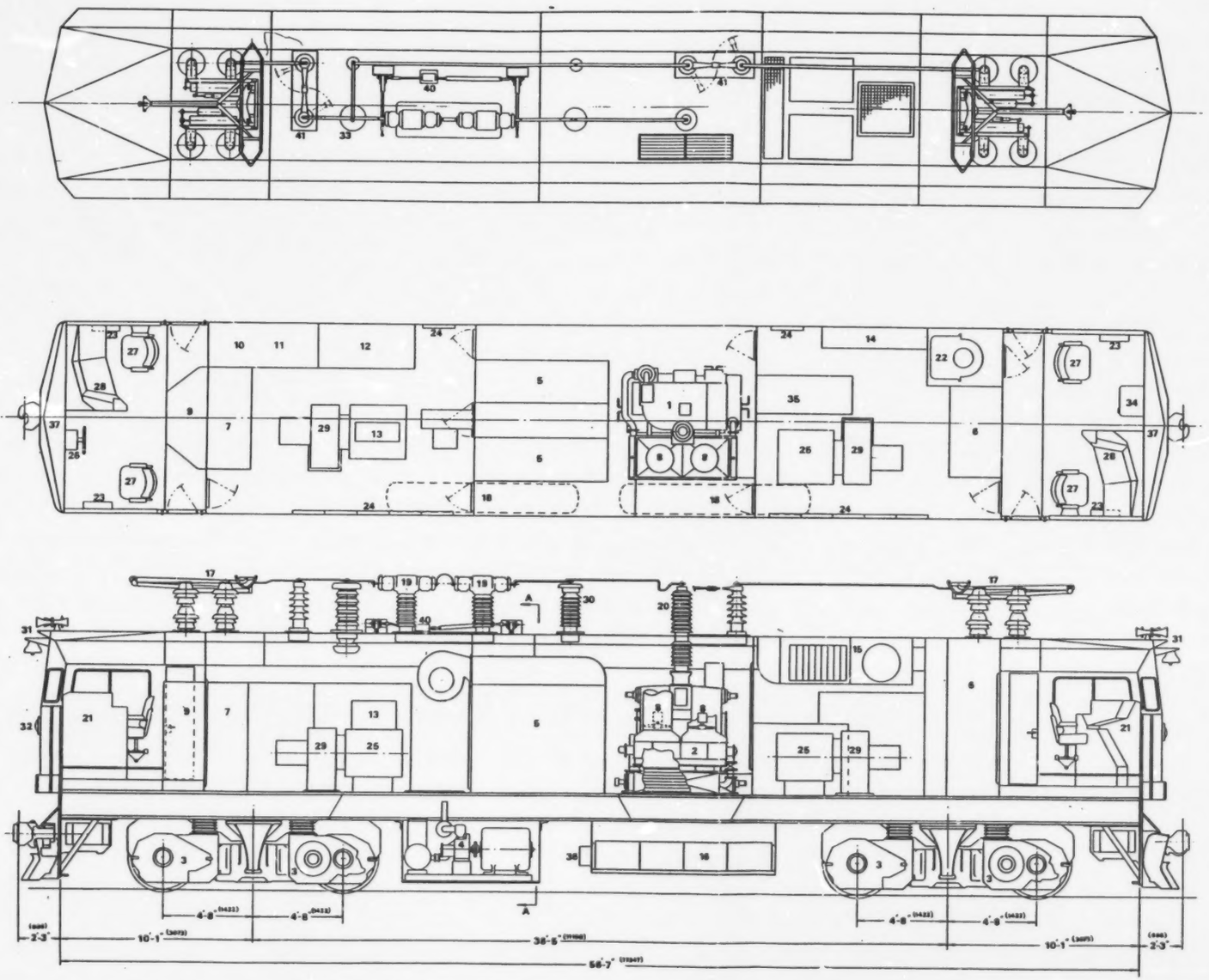
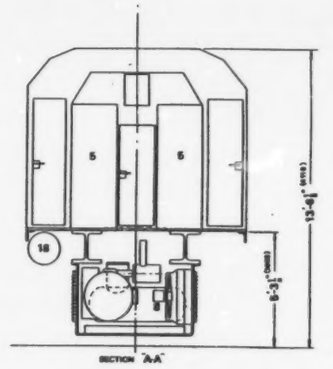
Figure 19b.





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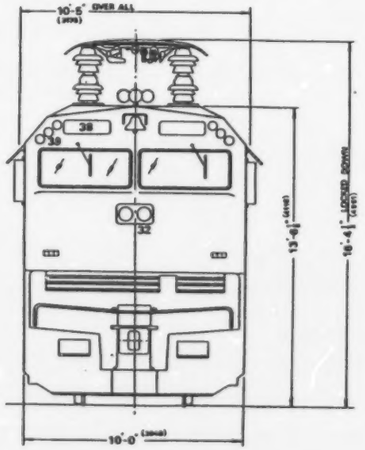

Figure 20a.

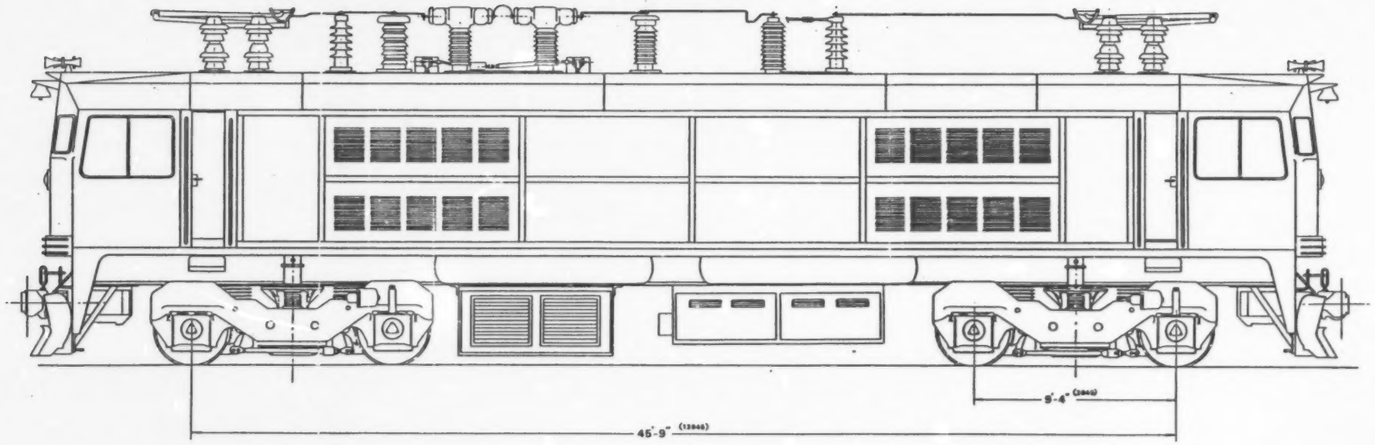

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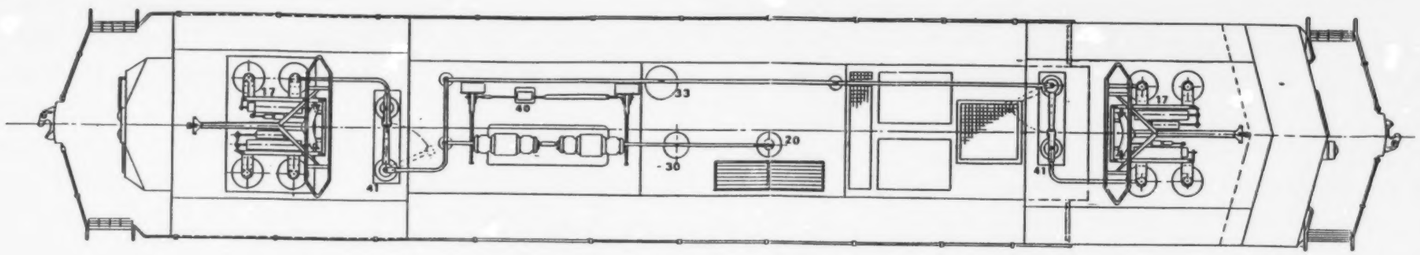
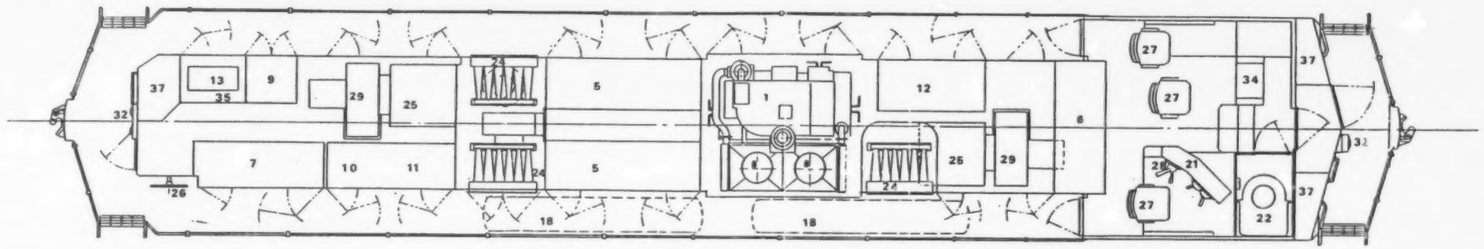
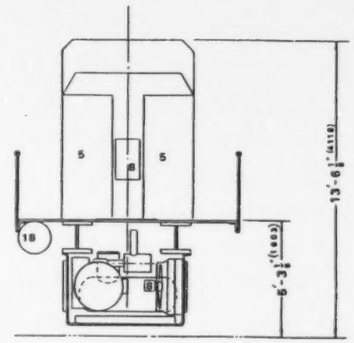
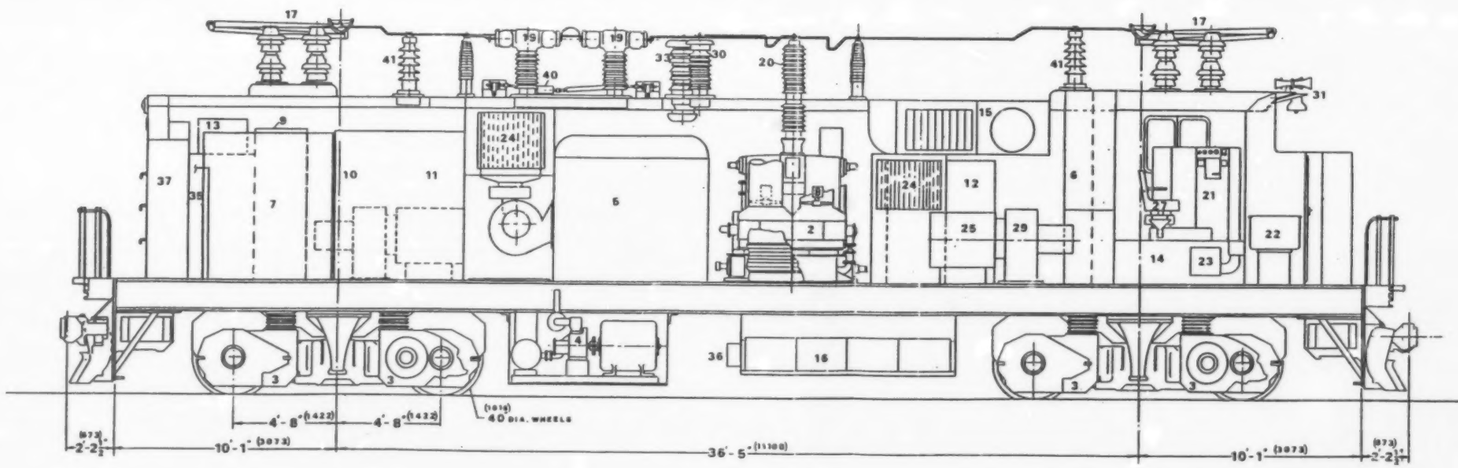
Figure 20b.









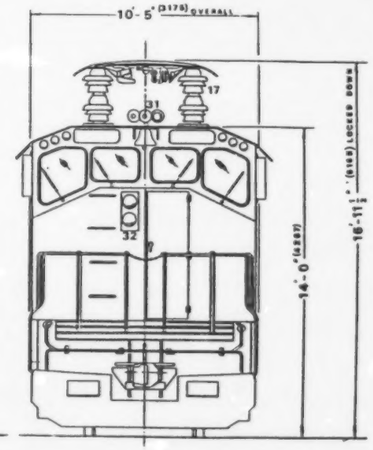


Figure 21a.

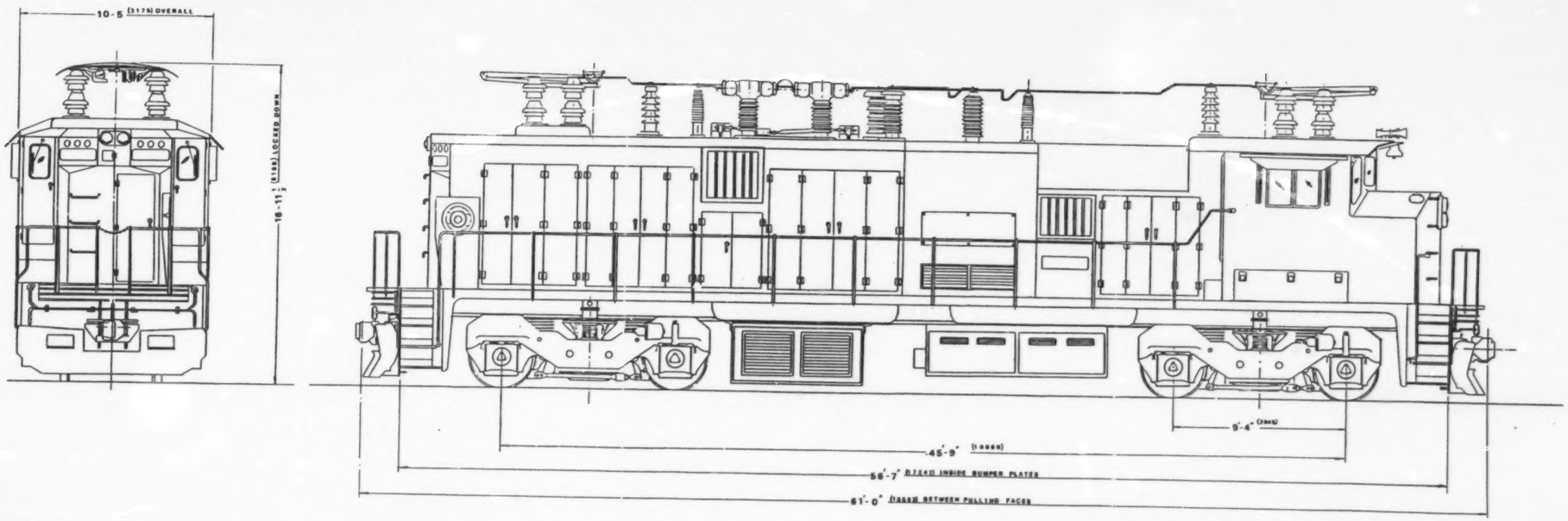


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Figure 21b.

4. LOCOMOTIVE CONCEPTUAL DESIGN

4.1 Introduction

Based on the locomotive layout work conducted in the feasibility phase of the project, locomotive designs were prepared in more detail for 4 and 6 axle electric locomotives employing conventional D.C. traction as proposed by GEC Canada. The designs incorporate the newest available equipment using oil cooling as opposed to the air-cooled converter scheme used in the feasibility layouts.

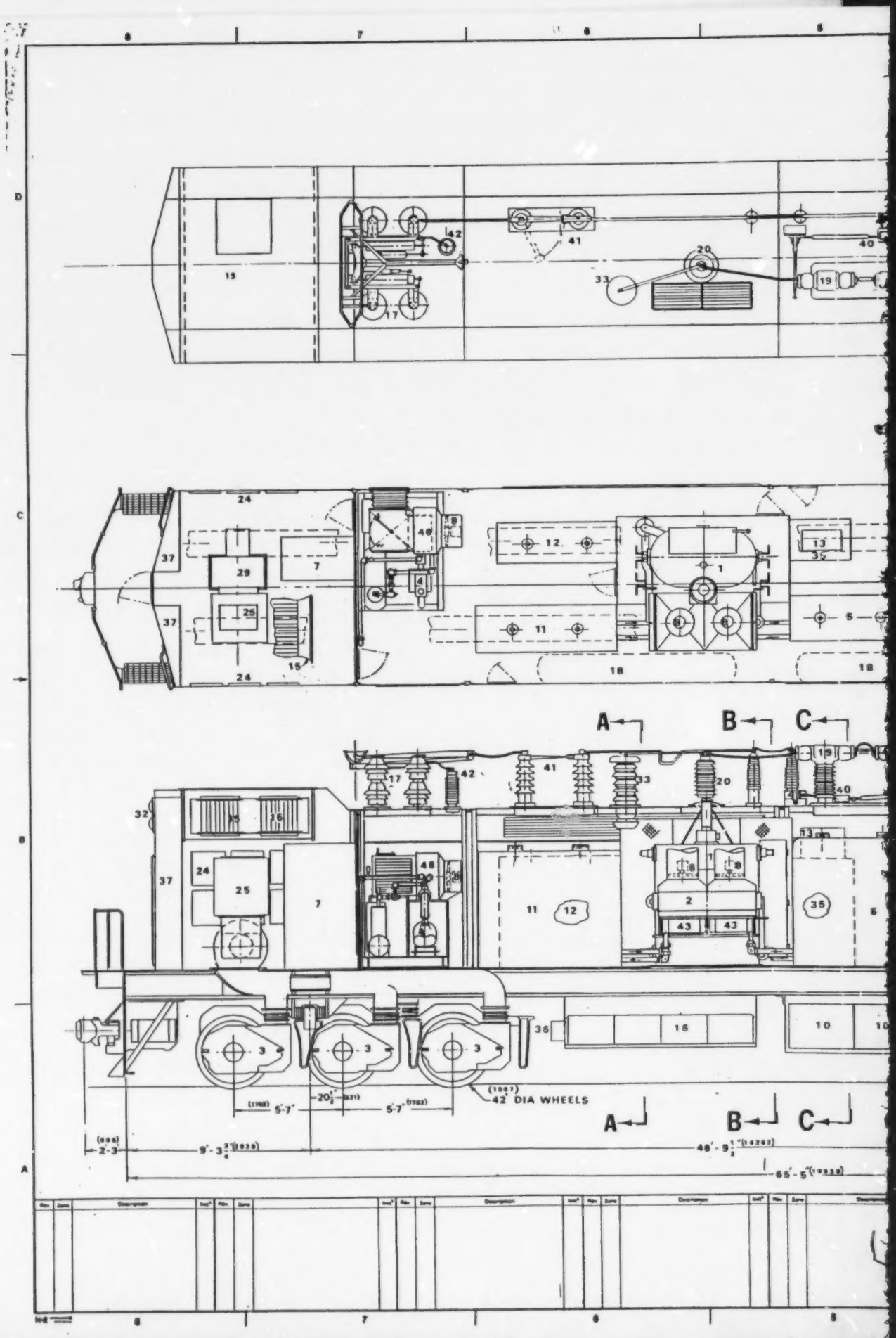
In addition, designs were carried out using 3-phase A.C. traction based on information supplied by BBC Canada. The equipment solution investigated here was based on the use of oil-cooled inverters and 4-quadrant input converters. Although AC traction uses components of larger size than conventional D.C. traction it was determined that either could be accomodated on narrow and wide-hood 4 and 6 axle locomotives of reasonable length.

4.2 C-C Tapered Wide Hood with DC Traction

This is considered the locomotive with the greatest possibility of acceptance by Canadian railways or heavy-haul North American industrial operators. A revised complement of GEC electrical equpment has been incorporated into the design (Figure 22a,b,c). The converter (5) and auxiliary inverter (11) are now both oil-cooled. Their heat exchangers (43) are mounted under those of the main transformer (2) and are cooled by air moved by twin ventilation fans (8). Cooling air flow into the section of the locomotive containing the transformer is by means of louvers mounted high up on the locomotive on both sides. The unfiltered air circulates to the bottom of the transformer cooling column and is drawn through the radiators after which it is exhausted through the roof of the locomotive.

Transformer secondary power is bussed to the converter and inverter. The converter consists of thyristor/diode bridges for control of motor armatures and fields. The inverter is also thyristor-controlled and supplies a fixed 60 Hz, 480 VAC, 3 phase AC output for locomotive auxiliary power.

The locomotive air compressor (4) is of the rotary-screw type, oil-cooled, and capable of 120 CFM at 140 PSIG continuously. Cooling of the compressor is by means of


A
B
C
42 DIA WHEELS
5'-7"
5'-7"
2'-3"
9'-3 3/4"
40'-9 1/2"
65'-5"

1- TRANSFORMER
2- TRANSFORMER RADIATOR
3- TRACTION MOTOR
4- AIR COMPRESSOR – MAIN
5- THYRISTOR / DIODE RECTIFIER
6- HIGH VOLTAGE EQUIPMENT No. 1 END
7- HIGH VOLTAGE EQUIPMENT No. 2 END
8- FAN
9- ELECTRONIC CUBICLE
10- POWER FACTOR CORRECTION EQUIPMENT
11- BATTERY CHARGER & AUXILIARY INVERTER
12- LOW VOLTAGE EQUIPMENT
13- AIR COMPRESSOR – AUXILIARY
14- BRAKE EQUIPMENT
15- RHEOSTATIC BRAKE UNIT
16- BATTERIES
17- PANTOGRAPH
18- AIR RESERVOIR
19- VACUUM CIRCUIT BREAKER
20- INPUT BUSHING
21- CONTROL STAND
22- TOILET
23- CAB HEATER
24- CARBODY AIR FILTER
25- CHOKE
26- HANDBRAKE
27- SEATS
28- BRAKE VALVES
29- TRACTION MOTOR BLOWER
30- POTENTIAL DIVIDER
31- HORN & BELL
32- HEADLIGHT
33- LIGHTNING ARRESTOR
34- REFRIGERATOR
35- POWER FACTOR CORRECTION CONT'L.
36- BATTERY ISOLATING SWITCH
37- SAND BOX
38- NUMBER BOX
39- CLASSIFICATION LIGHTS
40- EARTHING SWITCH
41- PANTOGRAPH ISOLATER
42- AIR FEED INSULATOR
43- OIL HEAT EXCHANGER
44-
45-
46- AFTERCOOLER
47- CONVENTIONAL CONTROL CUBICLE

SECTION A-A

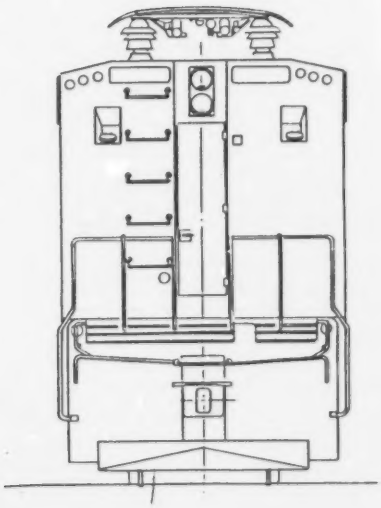
Figure 22a.

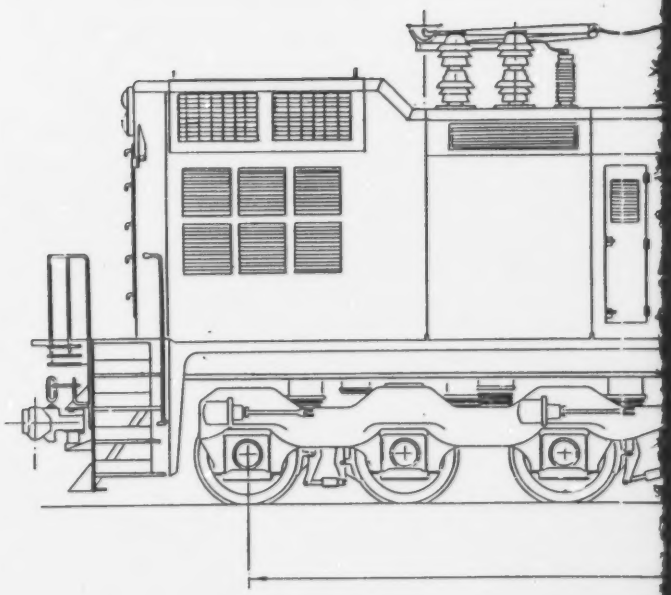
Rev.	Zone	Description	Date
A	D-1	DELETED Nº 44 & 45	
	D-1	Nº 85 WAS POWER SUPPLY	

Bombardier Inc.
Division des produits ferroviaires et diesel
Rail and Diesel Products Division
Montréal Québec Canada

GENERAL ARRG'T
ELECTRIC LOCOMOTIVE
SINGLE CAB - WIDE BODY - OIL COOLED (50-60)

AO
439180
1/3
A9B - 095110 - 000
A





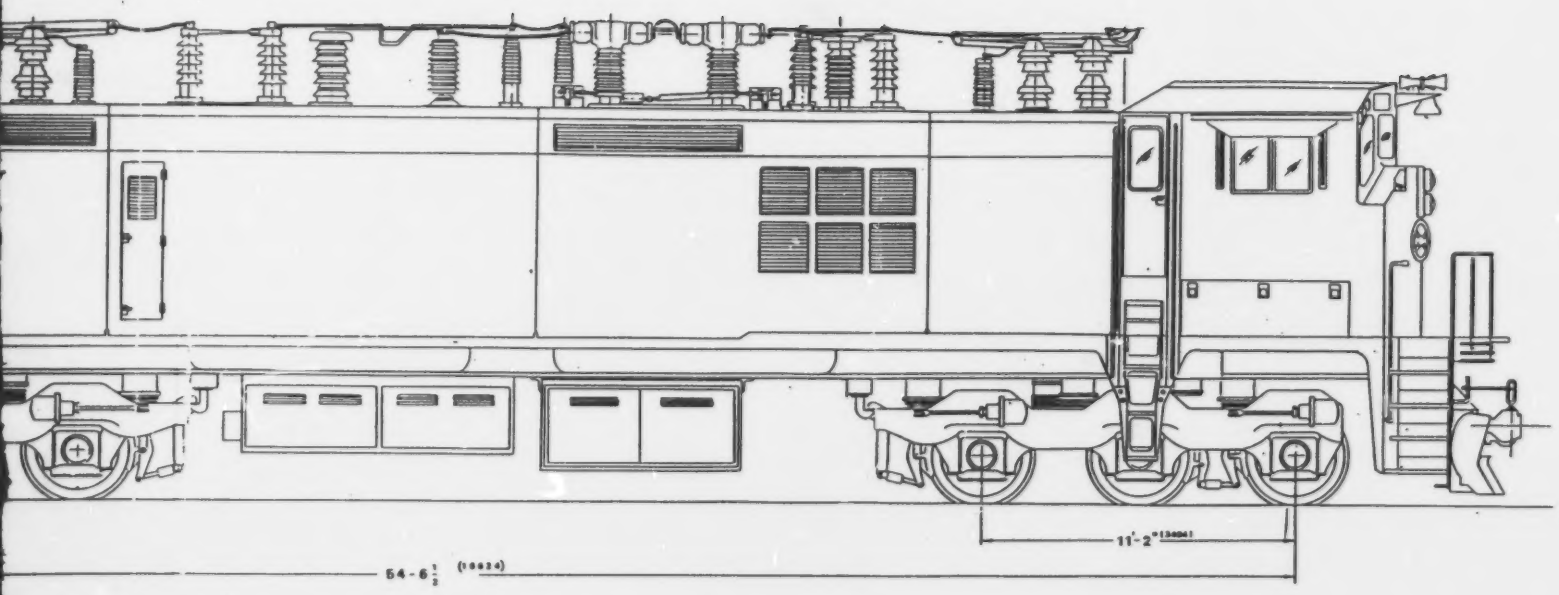
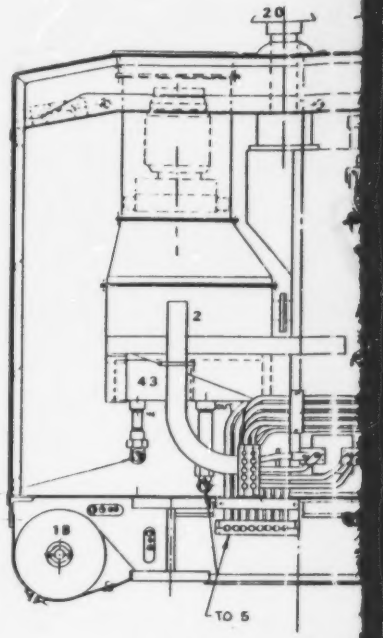
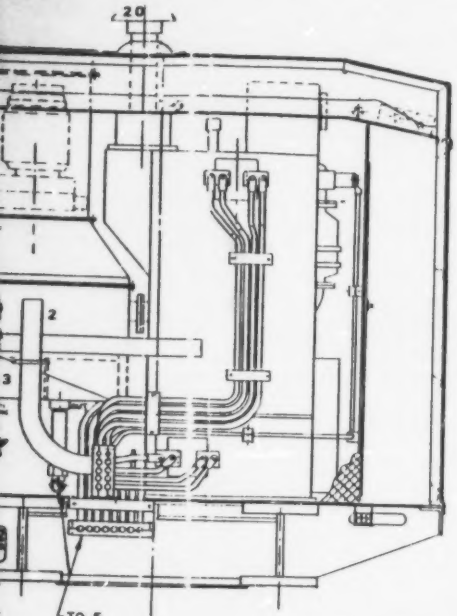


Figure 22b.

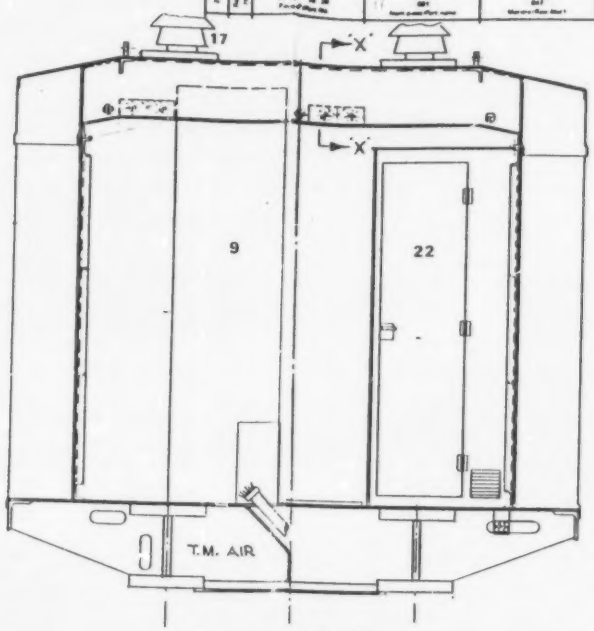
GENERAL ARRG'T.
ELECTRIC LOCO
A98-095110-000



— SECTION C-C

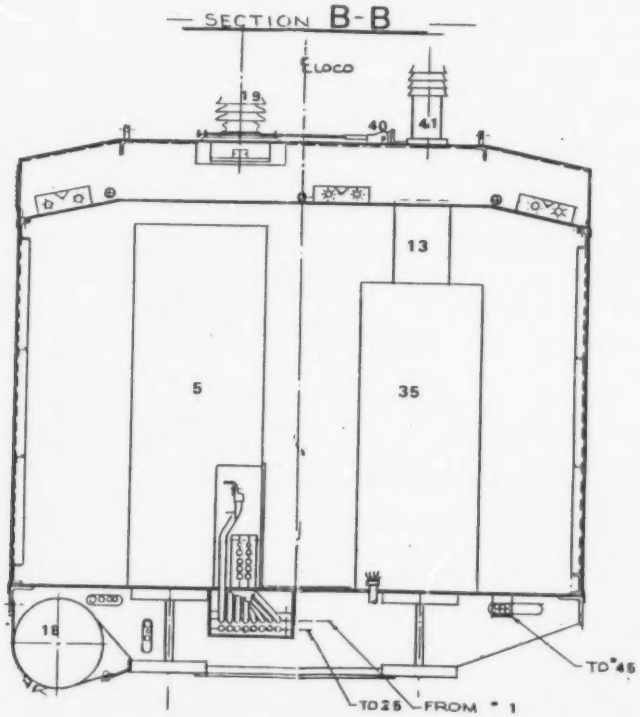


SECTION C-C



SECTION B-B

SECTION 'X-X'



SECTION D-D

NOTE :-
FOR LOCATION OF SECTION CUTS & IDENTIFICATION OF EQUIPMENT SEE SHEET 1

Figure 22c.

Rév.	Zone	Description	Init.
A	C-5	OIL PUMP Nº 44 DELETED SEE SHEET Nº 1	

Bombardier Inc.
Division des produits ferroviaires et diesel
Rail and Diesel Products Division
Montréal, Québec, Canada

GENERAL ARRG'T.
ELECTRIC LOCOMOTIVE

A98-095110-000 A

an oil-to-air heat exchanger arrangement (46) with electric motor drive and dampers to select winter/summer operation.

The front and rear equipment compartments are separate from that of the transformer compartment. In these areas air is drawn in through panel filters (24) located on the sides of the locomotive. The clean air passes through traction motor armature smoothing chokes (25) and is forced into ducts in the frame by blowers (29) for distribution to the traction motors. High voltage equipment cabinets (6, 7) are located in these areas to house power switchgear and transducers.

The rear locomotive equipment section contains the dynamic brake pod (15). Two motor-driven axial blowers force air through the dynamic brake resistor grids when the locomotive is in the electric braking mode.

The front locomotive equpment section contains the electronic cubicle [9], which controls the converter and inverter. A toilet is also located in this area.

The locomotive cab is of the "CN" type with a shortened short hood section. A standard control stand may be provided or, alternately as shown in Figure 22a, a control desk (21). Equipment compartment (47) forms the locomotive rear cab wall and houses conventional locomotive controls and indicators.

The roof supports the 50 KV equipment to include:

- 2 pantographs (17)
- 2 pantograph isolation switches (41)
- 2 air feed-throughs (42)
- 1 potential divider (30)
- 1 grounding switch (40)
- 1 vacuum circuit breaker assembly (19)
- 1 lightning arrestor (33)
- 1 input bushing (20)

Not all of this equipment will be required in all applications but it has all been included to study the worst-case installation condition.

The frame underside supports the battery boxes (16) and power factor correction equipment (10). The latter consists of capacitor banks switched on or off by bi-directional thyristor switches located in the converter. Isolating switchgear has been shown located in cabinet (35).

The trucks are of the standard Hi-Ad design used on diesel-electric locomotives. Three separately-excited DC traction motors are used in each truck whereby each motor handles approximately 1000 diesel-equivalent hp each.

Four roof sections are provided in a manner to facilitate removing and working on equipment mounted on the roof of the locomotive and in the body. The first roof section supports the leading-end pantograph and can be lifted off after disconnecting the flexible cables on the roof and opening the roof retaining clips to the side walls. After removal of the roof section the complete control cubicle (9) and blower/choke assembly can be lifted out. Equipment cabinet (6) is, however, a substantial structure welded into place on the floor and not meant for removal. For this reason a carline can be placed over it as shown.

The 2nd roof section supports the 50 kV vacuum circuit breaker assembly and other 50 kV equipment. Stability of the rear end of this section is provided by a carline located just to the front of the main transformer. After removal of this roof section a straight lift-out of the converter (5) is possible.

The 3rd roof section covers the transformer, inverter, and low voltage equipment. These can be lifted out after removal of the roof section. A carline stabilizes both this and the 4th roof section.

The 4th roof section supports the trailing pantograph and covers the air compressor. The compressor is skid-mounted and removable by straight lift out from the locomotive. Alternately, the side panel of the locomotive adjacent to the compressor can be removed and the unit slid out through this opening.

The aft compartment of the locomotive does not have a removable roof; but, instead, access is provided to interior equipment by lifting-off of the DB pod. As in the forward equipment section, cabinet (6) is a solid structure providing stability to the locomotive hoods and is not made removable. The blower/choke arrangement is designed for straight lift out from the locomotive. The bulkhead provides support for the 4th roof section.

4.3 B-B Narrow Hood with DC Traction

A layout is shown in Figure 23a,b for a four-axle narrow hood version of the locomotive discussed in section 4.2 above. With wheel diameters restricted to the 1016-1067 mm (40-42 in) range, traction motor limitations would restrict the power-handling capabilities of this locomotive to about 4000 diesel equivalent hp. To check equipment installation, however, the entire complement of the C-C locomotive equipment was included. In this case, inertial filters (24) are used to provide clean air to the traction motor blowers. The more limited roof space also requires outward-facing pantograph knuckles.

The cab is of the conventional "CN" design but is lowered because of the pantograph. The toilet (22) is located in the short hood. The electronic cubicle (9) is accessible from the cab, while the conventional control cubicle is shortened somewhat to provide space for the forward blower motor.

The air compressor (4) is packaged for underframe mounting. Power factor correction equipment (10) has been brought into the hoods and all high-voltage switchgear is located in cabinets (6, 35) since less equipment is required than on a 6-axle locomotive.

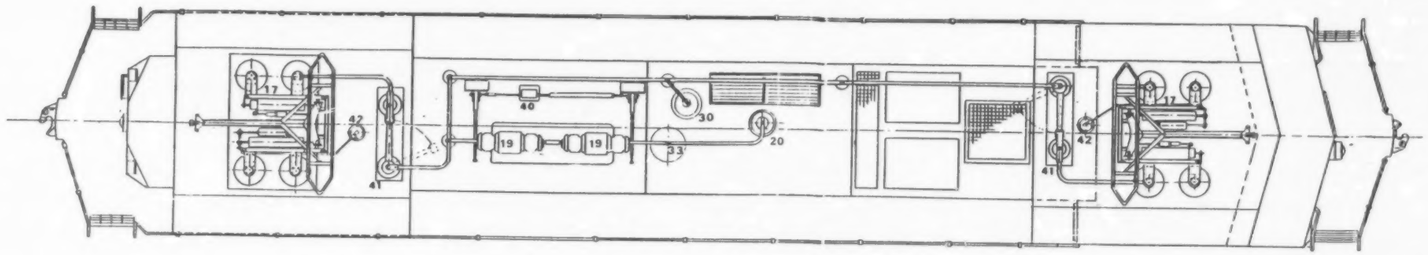
The roof section under the rear pantograph has been widened to full frame width in order to provide increased protection from the 50 kV on the pantograph. Similar protection has been added at the rear and front of the cab.

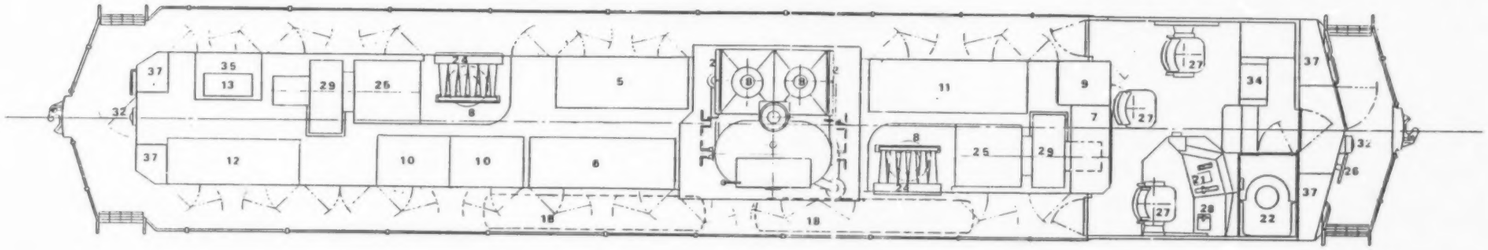
The DB pod (15) has been moved to a position between the transformer and cab, and has now been configured as a dual blower type using a single DC drive motor as is standard on diesel-electric locomotives

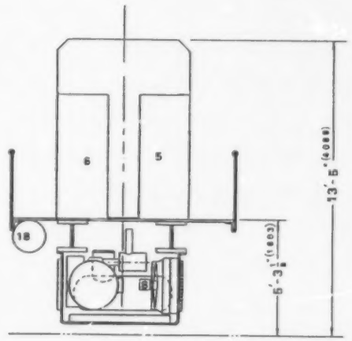
Detailed studies of roof equipment support and sectioning was not carried out with this locomtive.

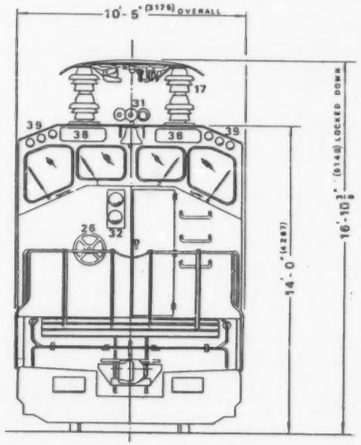
4.4 C-C Tapered Wide Hood with 3-phase AC Traction

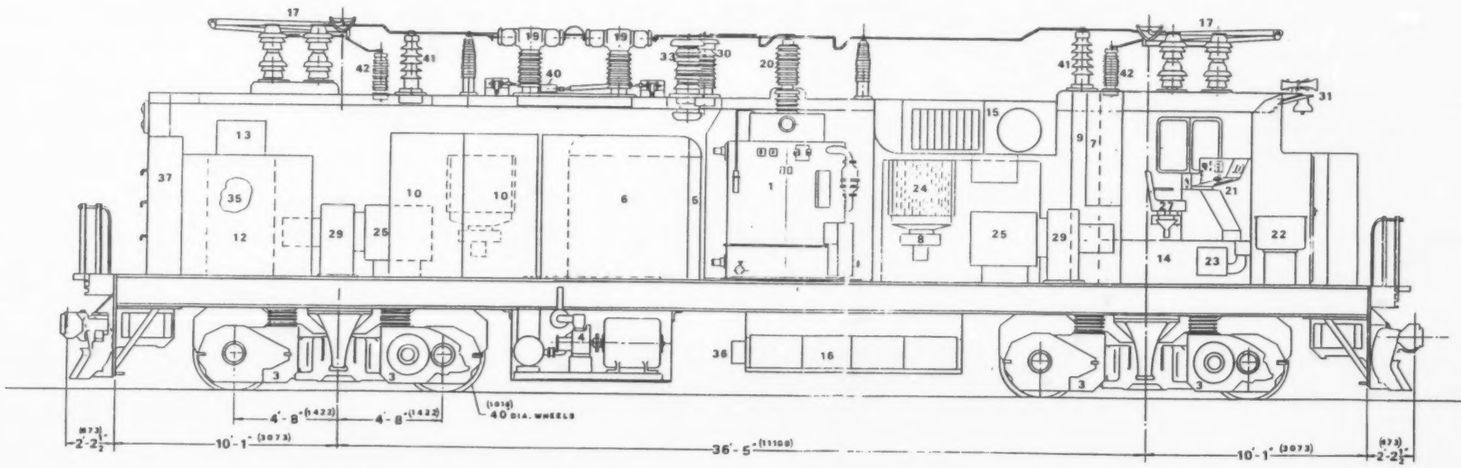
A conceptual locomotive layout was carried out using 3 phase AC traction and AC auxiliary equipment as recently applied by BBC on various European electric locomotives (Figure 24a,b).











1 TRANSFORMER
2 TRANSFORMER RADIATOR
3 TRACTION MOTOR
4 AIR COMPRESSOR - MAIN
5 THYRISTOR / DIODE RECTIFIER
6 HIGH VOLTAGE EQUIPMENT
7 CONVENTIONAL CONTROLS CUBICLE
8 FAN
9 ELECTRONIC CUBICLE
10 POWER FACTOR CORRECTION EQUIPMENT
11 BATTERY CHARGER & AUXILIARY INVERTER
12 LOW VOLTAGE EQUIPMENT
13 AIR COMPRESSOR - AUXILIARY
14 BRAKE EQUIPMENT
15 RHEOSTATIC BRAKE UNIT
16 BATTERIES
17 PANTOGRAPH
18 AIR RESERVOIR
19 VACUUM CIRCUIT BREAKER
20 INPUT BUSHING
21 CONTROL STAND
22 TOILET
23 GAS HEATER
24 INERTIAL AIR FILTER
25 CHOKE
26 HANDBRAKE
27 SEATS
28 BRAKE VALVES
29 TRACTION MOTOR BLOWER
30 POTENTIAL DIVIDER
31 HORN & BELL
32 HEADLIGHT
33 LIGHTNING ARRESTOR
34 REFRIGERATOR
35 POWER FACTOR CORRECTION CONTROL
36 BATTERY ISOLATING SWITCH
37 SAND BOX
38 NUMBER BOX
39 CLASSIFICATION LIGHTS
40 EARTHING SWITCH
41 PANTOGRAPH ISOLATOR
42 AIR FEED INSULATOR

4'-8" (1422)
4'-8" (1422)
(1016) 40 DIA. WHEELS
2'-2½" (673)
10'-1" (3073)
36'-5" (11100)
10'-1" (3073)
2'-2½" (673)

13'-5" (4089)
5'-3" (1603)
10'-5" (3176) OVERALL
16'-10½" (5148) LOCKED DOWN
14'-0" (4267)

Figure 23a.

Rev.	Zone	Description	Ins'd	Rev.	Zone	Description	Ins'd	Rev.	Zone	Description	Ins'd	Rev.	Zone	Description	Ins'd	Rev.	Zone	Description	Ins'd
																A		REF # 35 MAIS POWER SUPPLY JULY 9 83	

PROJECTION

TOLERANCES FOR DIMENSIONS SHOWN INDICATION CONTRAIRE

METRIC .XX ±.03 .XXX ±.010 .XXXX ±.0005

DECIMAL X.XX ±1/32 X.XXX ±.010 FRAC (EXP) ±1/16 ANGLES 2½° CHAMFERS 2°

DRAWING NO. A98-095090-000

SIZE A0

SCALE 1:14 1/2

SHEET A98-095100-000

Bombardier Inc.
Division des produits ferroviaires et divers
Rail and Diesel Products Division
Montréal Québec Canada

GENERAL ARRANGEMENT
ELECTRIC LOCOMOTIVE
ONE CAB - NARROW HOOD (60 - SERIES)

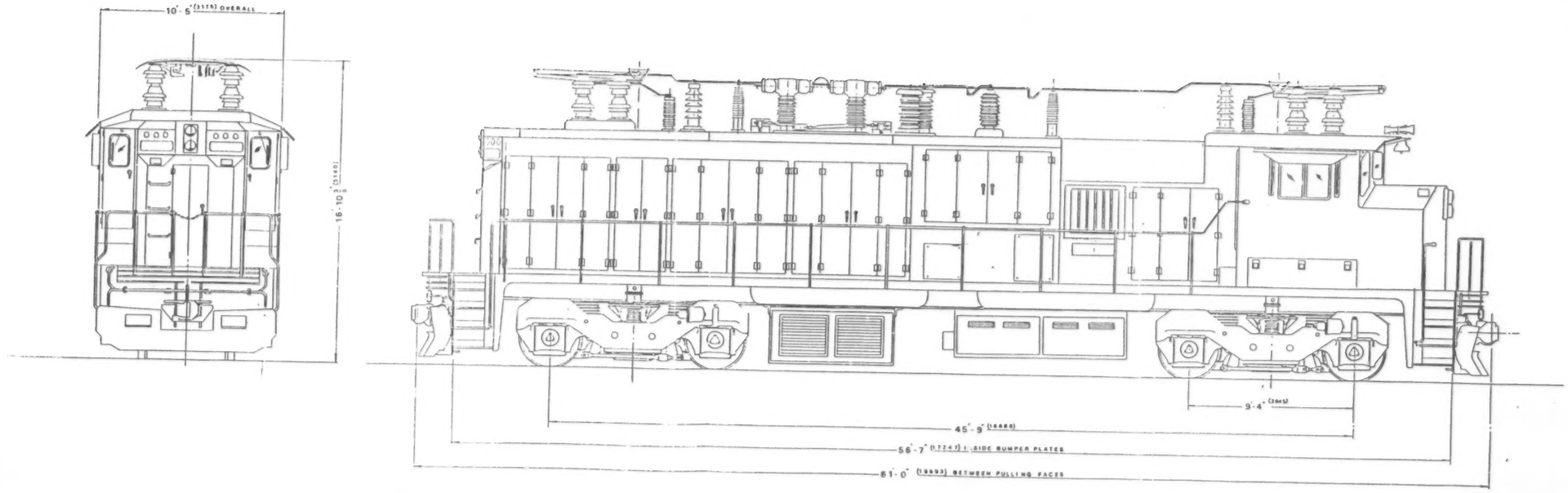


Figure 23b.

			Bombardier Inc.	
			GENERAL ARRG'T.	
		AO	ELECTRIC LOCO.	
		429150	1:1	A98-095100-000 A

1 TRANSFORMER
3 TRANSFORMER RADIATOR
5 TRACTION MOTOR
6 AIR COMPRESSOR – MAIN
8 4-QUADRANT CONTROLLER
6 HIGH VOLTAGE EQUIPMENT No. 1 END
7 HIGH VOLTAGE EQUIPMENT No. 2 END
8 PAN
9 TRACTION INVERTER
10
11 AUXILIARY INVERTER
13 LOW VOLTAGE EQUIPMENT
12 AIR COMPRESSOR – AUXILIARY
14 BRAKE EQUIPMENT
15 DYNAMIC BRAKE UNIT
16 BATTERIES
17 PANTOGRAPH
18 AIR RESERVOIR
19 VACUUM CIRCUIT BREAKER
20 INPUT BUSHING
21 CONTROL STAND
22 TOILET
23 CAB HEATER
24 CARBODY AIR FILTER
25 CHOKE
32 HANDBRAKE
33 SEATS
34 BRAKE VALVES
35 TRACTION MOTOR BLOWER
36 POTENTIAL DIVIDER
37 HORN & BELL
38 HEADLIGHT
39 LIGHTNING ARRESTOR
40 REFRIGERATOR
39 ELECTRONIC CONTROLS No. 1 END
40 ELECTRONIC CONTROLS No. 2 END
27 SAND BOX
28 NUMBER BOX
29 CLASSIFICATION LIGHTS
40 EARTHING SWITCH
41 PANTOGRAPH ISOLATOR
43 AIR FEED INSULATOR
43 OIL HEAT EXCHANGER
44 PUMP
45 DYNAMIC BRAKE UNIT CONTACTOR CUBICLE
46 HEAT EXCHANGER
47 CONVENTIONAL CONTROL CUBICLE
48 2nd HARMONIC FILTER

SECTION A-A

51 DIA WHEELS

Rev.	Zone	Description	Date
A		REF Nº 10 DELETED REF Nº 48 WAS MOTOR/BRAKE SWITCH	

Bombardier Inc.
Division des produits ferroviaires et divers
Rail and Diverse Products Division
Montreal Quebec Canada

GENERAL ARRG'T
3 ELECTRIC LOCOMOTIVE
SIMPLE CAB – SINGLE CAB – DOUBLE CAB (50-60)

A98 - 095120 - 000 A

Figure 24a.

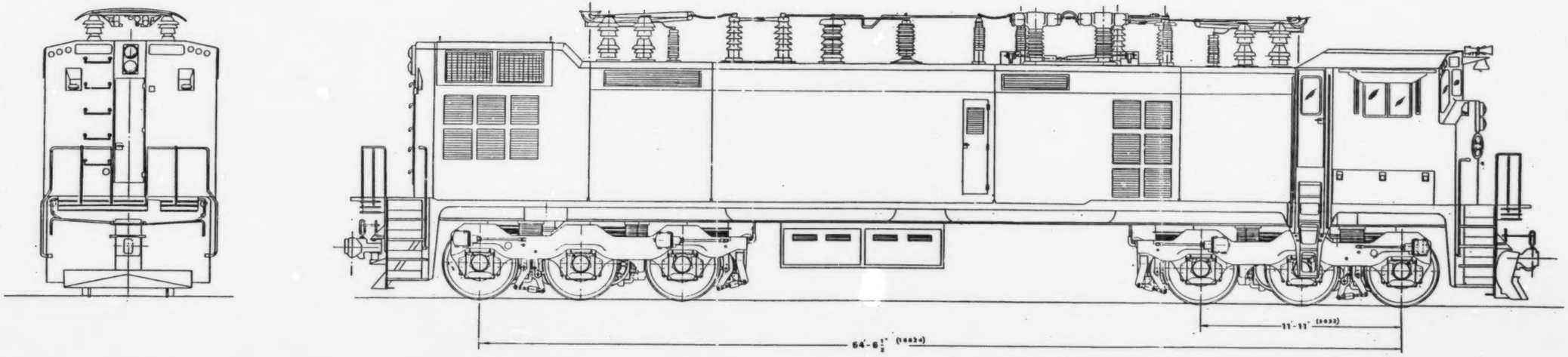


Figure 24b.

GENERAL ARRG'T.
ELECTRIC LOCO
A98 - 095120 -000 A

The same transformer has been assumed as in section 4.2 but with altered windings. The transformer secondary voltage is applied to two 4-quadrant controllers (5) from which an on-board DC bus is derived. An alternate system - perhaps more applicable to North American railroading conditions - would replace these controllers by simpler thyristor/diode bridges, but the above solution was selected to provide a worst case installation situation.

The DC bus is applied to inverters (9) for control of 3-phase AC traction motors on a per-truck basis. The motors used are variants of the BBC 3-phase AC motor developed for use on North American diesel-electric locomotives for up to 1000 diesel-equivalent hp per axle. A wheel diameter of 1295 mm (51 in) was chosen to investigate the impact of larger wheel sizes on equipment installation space in the locomotive body.

An auxiliary inverter group (11) is also connected to the DC bus. Three separate inverters are used for supply of individual truck and common auxiliaries. The common auxiliaries (such as the air compressor) can be switched between two inverters in case one unit malfunctions.

Because of the double power conversion process associated with 3-phase AC traction on electric locomotives, considerably more equipment is required resulting in a more cramped equipment configuration. Three hood and four roof sections are used, as was the case of DC traction but the divisions between sections were shifted in some cases.

Chokes are required with 3-phase AC traction motors and are cooled by traction motor cooling air. They are, however, now of the 3-phase AC type and must be provided with an appropriate bridging contactor in the immediate vicinity (6, 7). Relatively little DC switchgear is required, however, enabling reduction in the size of these cabinets.

The auxiliary inverter (11) is provided with its own forced-air cooling system (8) utilizing filtered air from the aft clean air compartment. The air is blown over input chokes mounted on top of the low voltage equipment compartment (12) and down through the top of the individual inverters to exit at the bottom near the air compressor.

The air compressor has been reconfigured slightly by turning of the cooler 90° in order to provide more width to the transverse passageway.

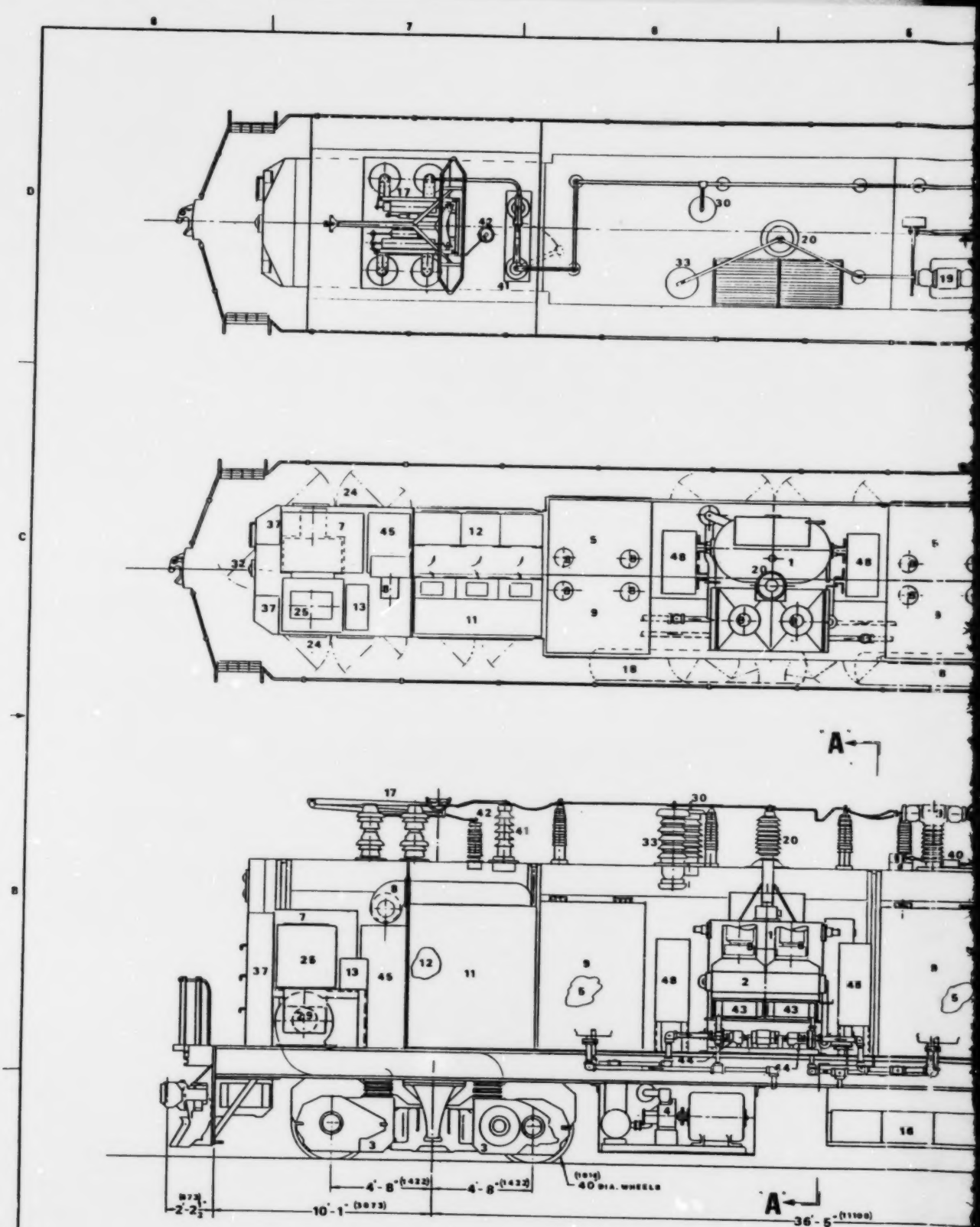
Controls are generally more voluminous with 3-phase AC traction than with DC traction. Two cabinets have been provided (35, 36) for control on a per truck basis.

The cab is similar to that developed previously for use with the locomotives equipped with DC traction.

4.5 B-B Narrow Hood with 3-Phase AC Traction

The introduction of the 3-phase AC traction equipment used on the 6-axle wide hood locomotive discussed in section 4.4 above into a B-B narrow hood locomotive was attempted and led to the configuration depicted in Figure 25a,b. The main block of transformer, 4-quadrant controllers, and inverters is placed in the middle of the locomotive. The major problem encountered is in finding sufficient space for the air-handling equipment. Insufficient space exists for installation of inertials and the filtration provided by the few panel filters depicted would provide marginal filtration at best.

The locomotive could be provided with 1016 or 1067 mm (40 or 42 in) wheels as shown in which case approximately 5000 diesel-equivalent hp can be realized from the locomotive using the existing BBC North American traction motors. More powerful motors can be applied but would require more space in the trucks and more equipment in the hoods. A longer locomotive would be required.


17
30
20
33
19
24
37
7
45
12
5
48
1
32
25
13
11
9
18
A
42
41
40
2
43
44
4
3
16
4'-8"(1422)
4'-8"(1422)
40 DIA. WHEELS
2'-2½"
10'-1"(3073)
36'-5"(11100)

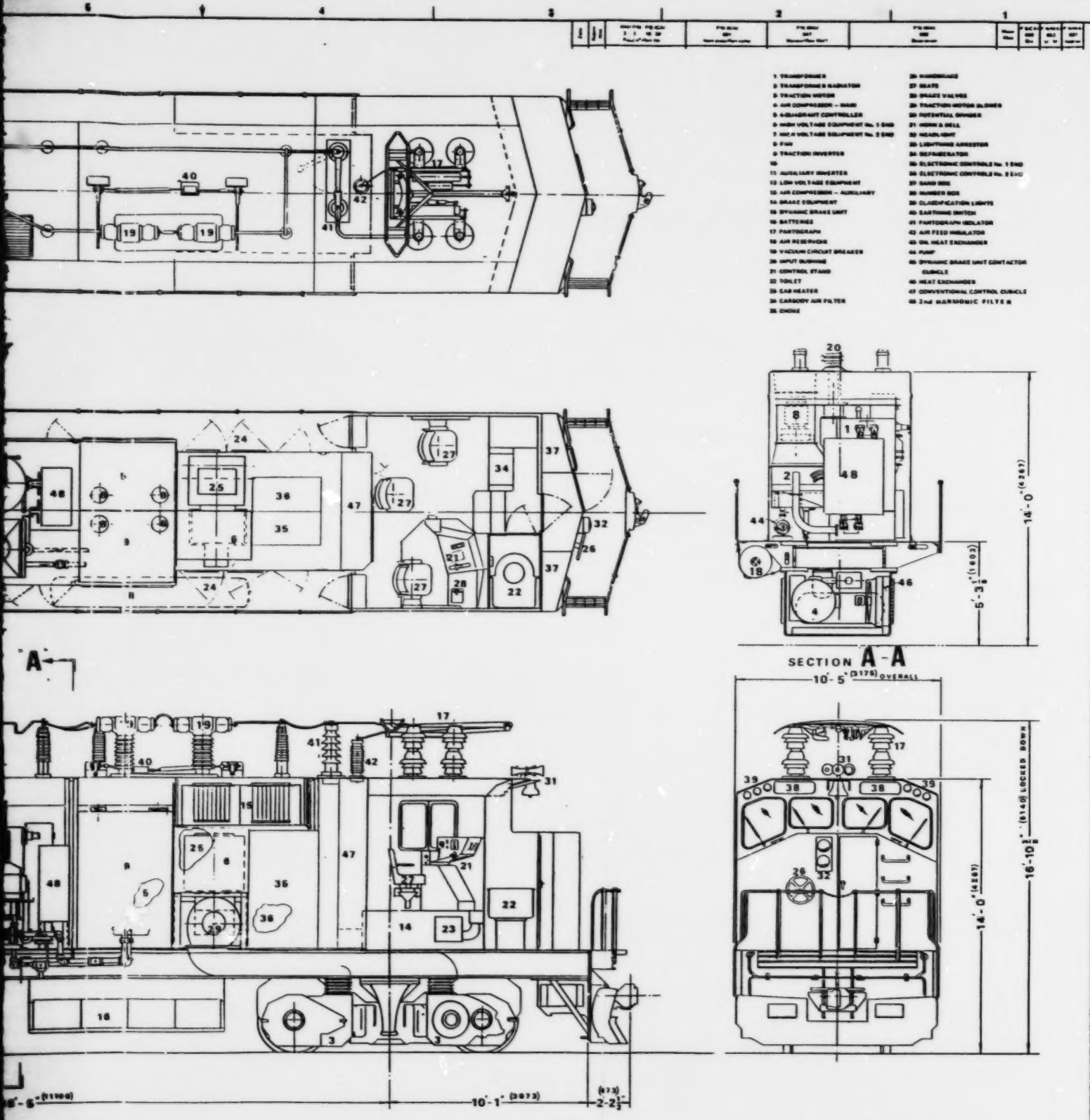
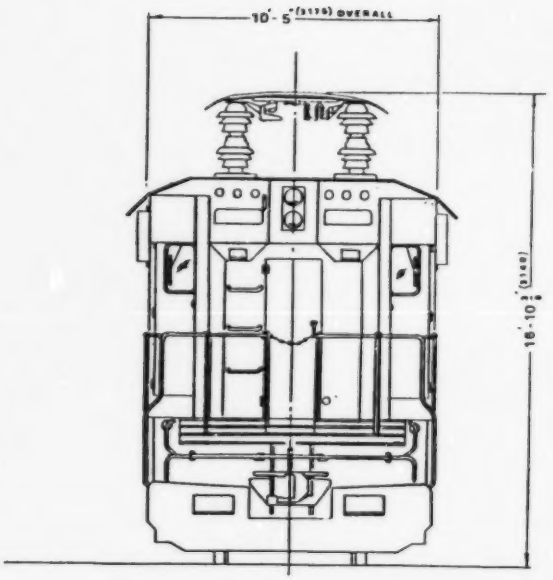
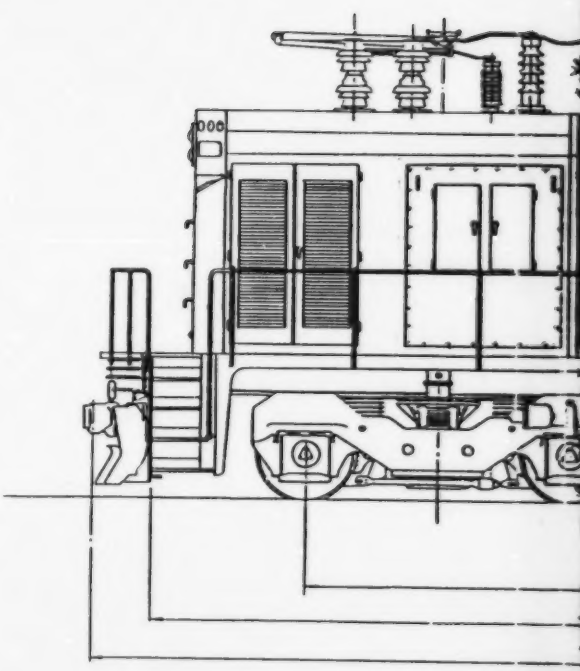

SECTION A-A
10'-5" (3175) OVERALL
14'-0" (4267)
16'-10 1/2" (5144) LOCKED BROWN
5'-3 1/8" (1603)
10'-1" (3073)
2'-2 1/2"

Figure 25a.


10' - 5" (3170) OVERALL
16' - 10 1/2" (5160)



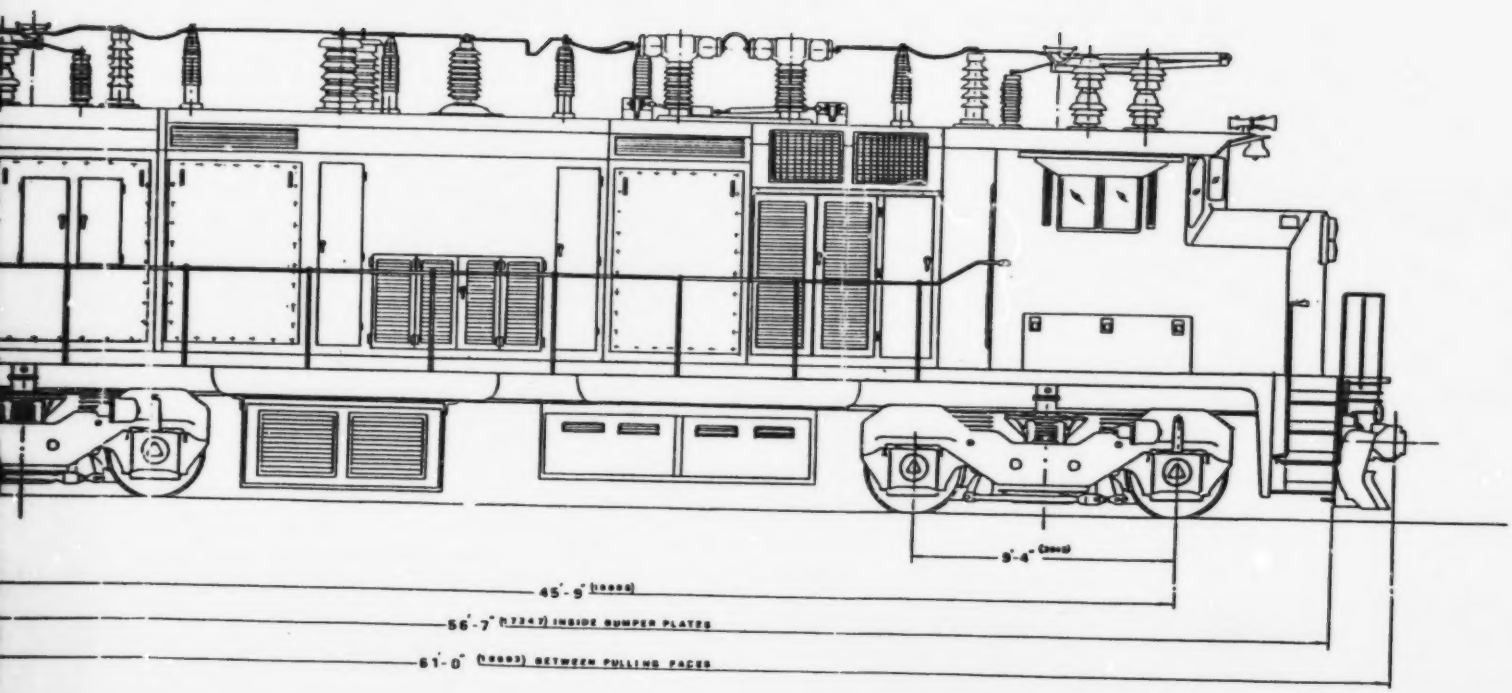


Figure 25b.

			GENERAL ARRG'T.
			3 ELECTRIC LOCO.
			A98-095130-000 A

5. PRELIMINARY DESIGN

5.1 Areas of Investigation

The major areas of locomotive system and equipment investigation were as follows:

- Truck and locomotive frame modifications to accommodate larger wheel diameters.
- Cabling and air duct arrangements.
- Roof structure and support.
- Weight study of C-C electric locomotive with DC traction.
- Rotary air compressor packaging.
- Auxiliary power systems.
- Traction power systems.

5.2 Truck Modifications to Accomodate Larger Wheel Diameters

It may be necessary in electric locomotive trucks to allow more space than available on conventional diesel-electric trucks for more powerful drive components. The gearset, in particular, requires as many teeth as possible if an acceptable wear is to be expected at the high tractive efforts demanded of these locomotives.

Any increase in the number of teeth, assuming constant root thickness, must result in an increase in axle center to motor shaft center distances and, hence, a requirement for more space in the longitudinal direction in the truck. Concomitantly, the enlarged main gear forces an increase in the wheel diameter in order to maintain clearances to the top of rail.

Existing DC traction motors must be increased in volume if operation with over 1000 diesel-equivalent hp per axle is envisioned. Since this is not possible in length because of the gauge restriction motor diameter must be increased. This leads again to a requirement for larger wheels since the center-to-center distance will increase.

To obtain more power 3-phase AC traction motors can either be increased in volume, operated at higher voltages, or run at higher speeds - the latter option only applying to these motors since DC traction motors are usually working at their commutator limits when the locomotive is running at high speed.

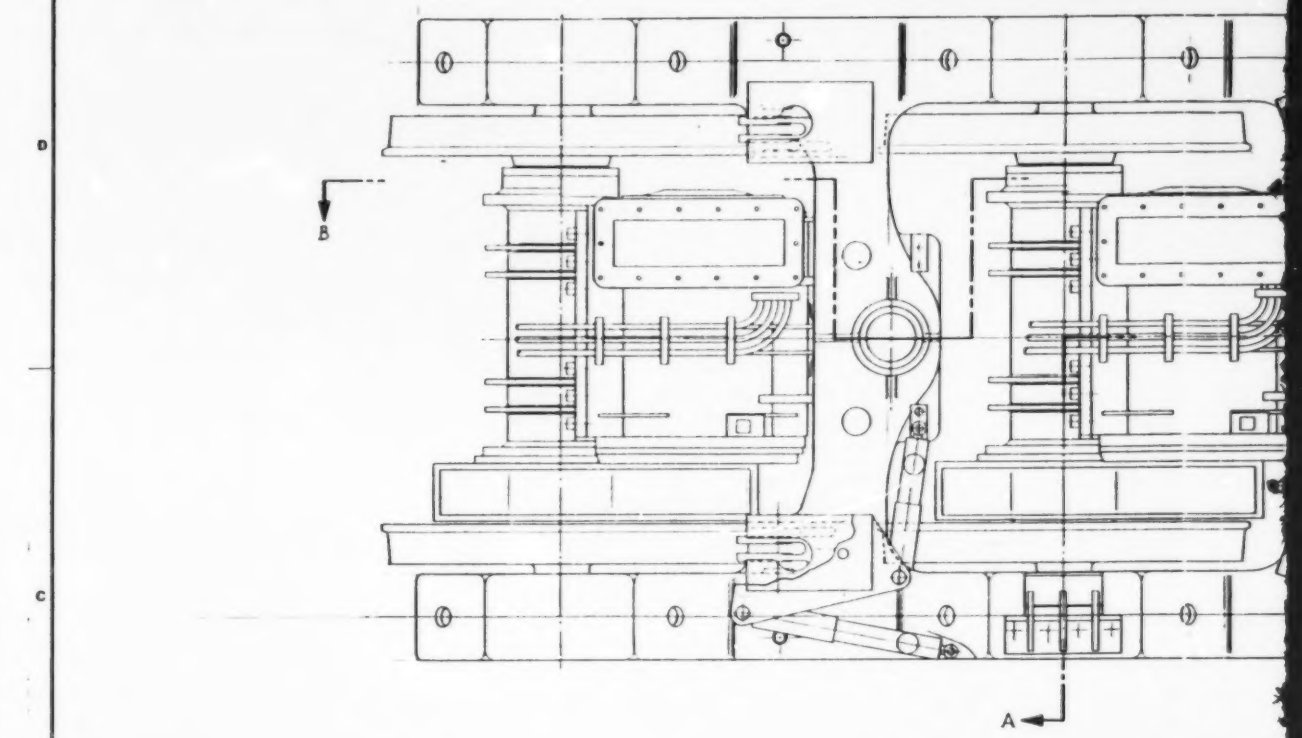
Two motors were considered in regard to truck installation - the BBC 6 FRA 4073 3-phase AC asynchronous and the GEC G416 AZ separately-excited DC traction motor.

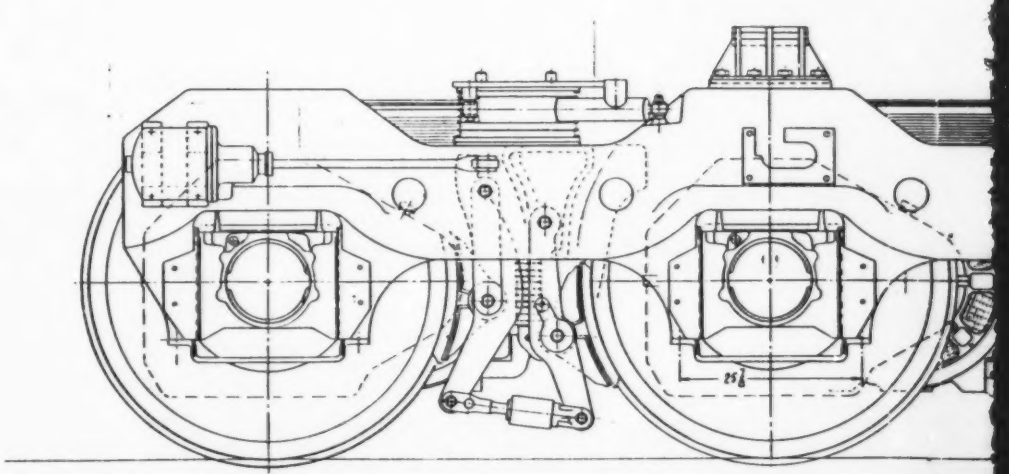
The BBC motor fits the existing truck frames since it was designed to replace the CGE 752 DC traction motor in Canadian diesel-electric locomotive applications for traction power (into the alternator) of up to 1000 hp per axle. As used on a 3-phase AC retrofit 4000 hp diesel-electric locomotive the main gear has 79 teeth and the pinion 16 for a gear ratio of 4.94. A new wheel diameter of 1067 mm (42 in) is preferred to realize an acceptable clearance under the gearbox. The motor is operated at a rated maximum speed of 3173 RPM, which, for even worn wheels, allow locomotive operation to 120 km/h (75 mph) with this gear ratio.

This same BBC motor can be used on a B-B electric locomotive of up to at least 5000 diesel-equivalent hp or C-C up to 6000 diesel equivalent hp without mechanical changes to either the motor or the existing truck. The higher power would be obtained by operating the motor at voltages higher than attainable from the alternator on a diesel-electric locomotive. Further increases in power will probably require a larger diameter motor and/or higher operation speed.

Larger wheels would allow a larger gear ratio and, therefore, a higher motor operating speed. The extreme case of increasing wheel diameter to 1295 mm (51 in) was the subject of a drafting study (Figure 26) on the existing 6-wheel Hi-Ad truck.

The larger wheels create an interference with the first and second truck transoms. Length must be added to the side frames, the transoms modified to fit the wheels, and the center pin relocated. There will be a 114 mm (4.5 in) increase in inter-axle spacing for a total 228 mm (9 in) overall truck length increase. This will present no problem for the electric locomotive underframe equipment since there is no fuel tank slung between the trucks.


B
A



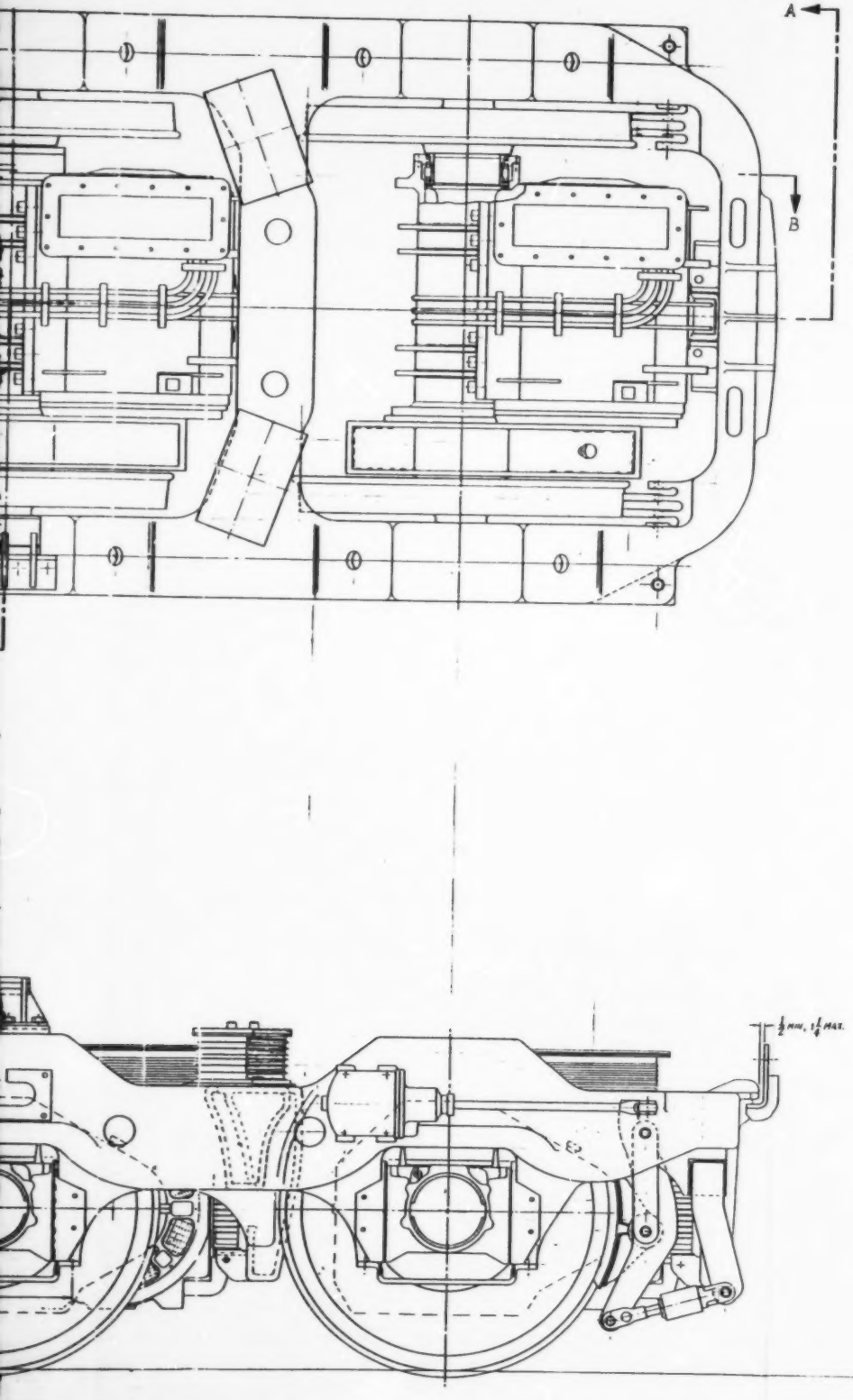
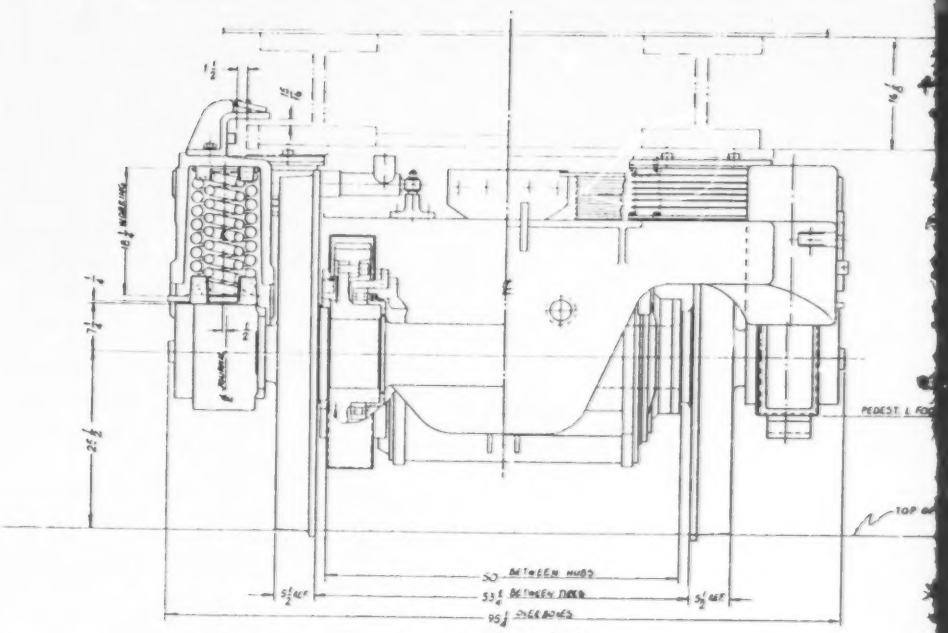
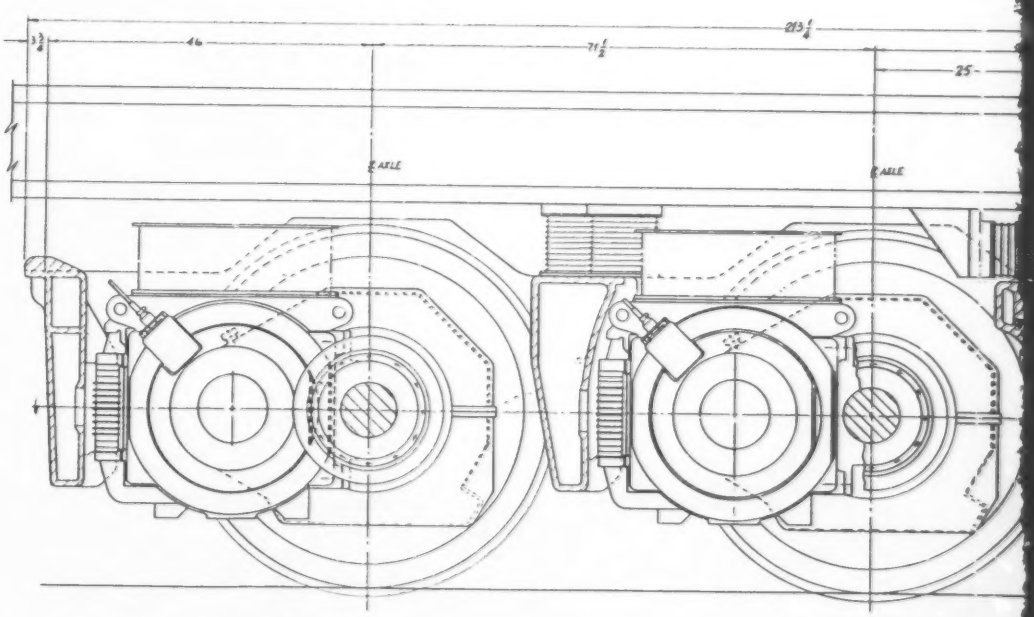


Figure 26a.

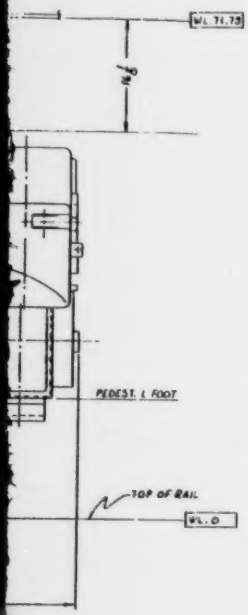
Bombardier Inc. Division des produits ferroviaires et diesel / Rail and Diesel Products Division, Montreal, Quebec, Canada			
A40-005840-000 / 4033-0-005360	MOTOR TRUCK ARRG'T		
A98-095120-000	ELECTRIC LOCOMOTIVE		
ELECTRK LOCO	AO		
EWO:439160	1/8	1/2	A40-005980-000

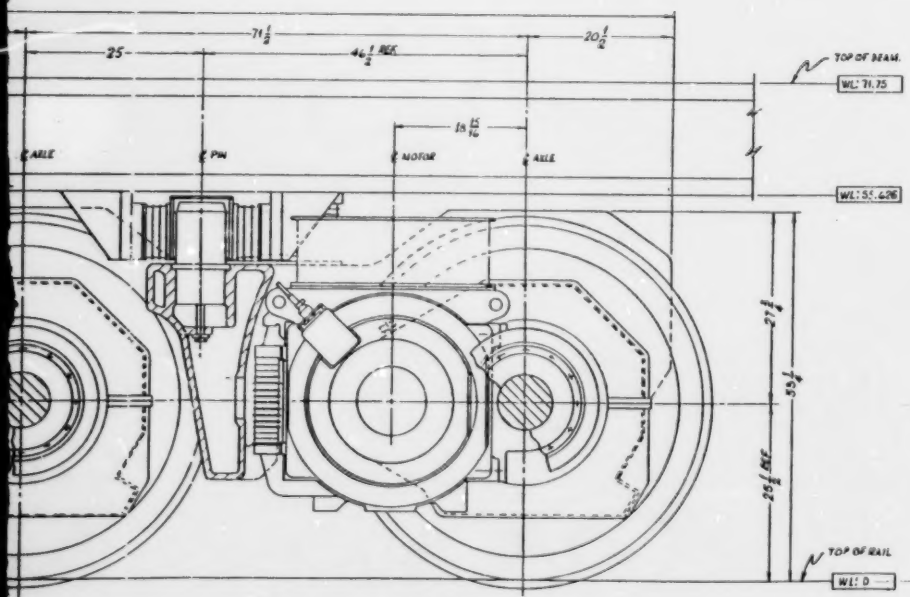


SECTION 'A-A'



SECTION 'B-B'





ON 'B-B'

Figure 26 b.

Bombardier Inc. Division des produits ferroviaires et diesel / Rail and Diesel Products Division, Montreal Québec, Canada			
Client/Customer: MOTOR TRUCK ARR'G'T			
Sujet/Subject: ELECTRIC LOCOMOTIVE			
N° référence/reference: A40-005840-000 / 4033-Q-005260			
N° commande/Order No.: A98-095120-000			
N° dessin/Drawing: ELECTRIC LOCO	AO		
N° commande client/Customer Order No.: EWD: 439160	Échelle/Scale: 1/8	Feuille/Sheet: 2/2	N° Dessin/Drawing No.: A40-005980-000

The brake arrangement will be modified by extensions of 114 mm (4.5 in) to the cylinder push rods. Different brake shoes will be required to suit the 1295 mm (51 in) wheel diameter.

The frame modifications are minor compared to the truck changes required; essentially a new truck design will be needed.

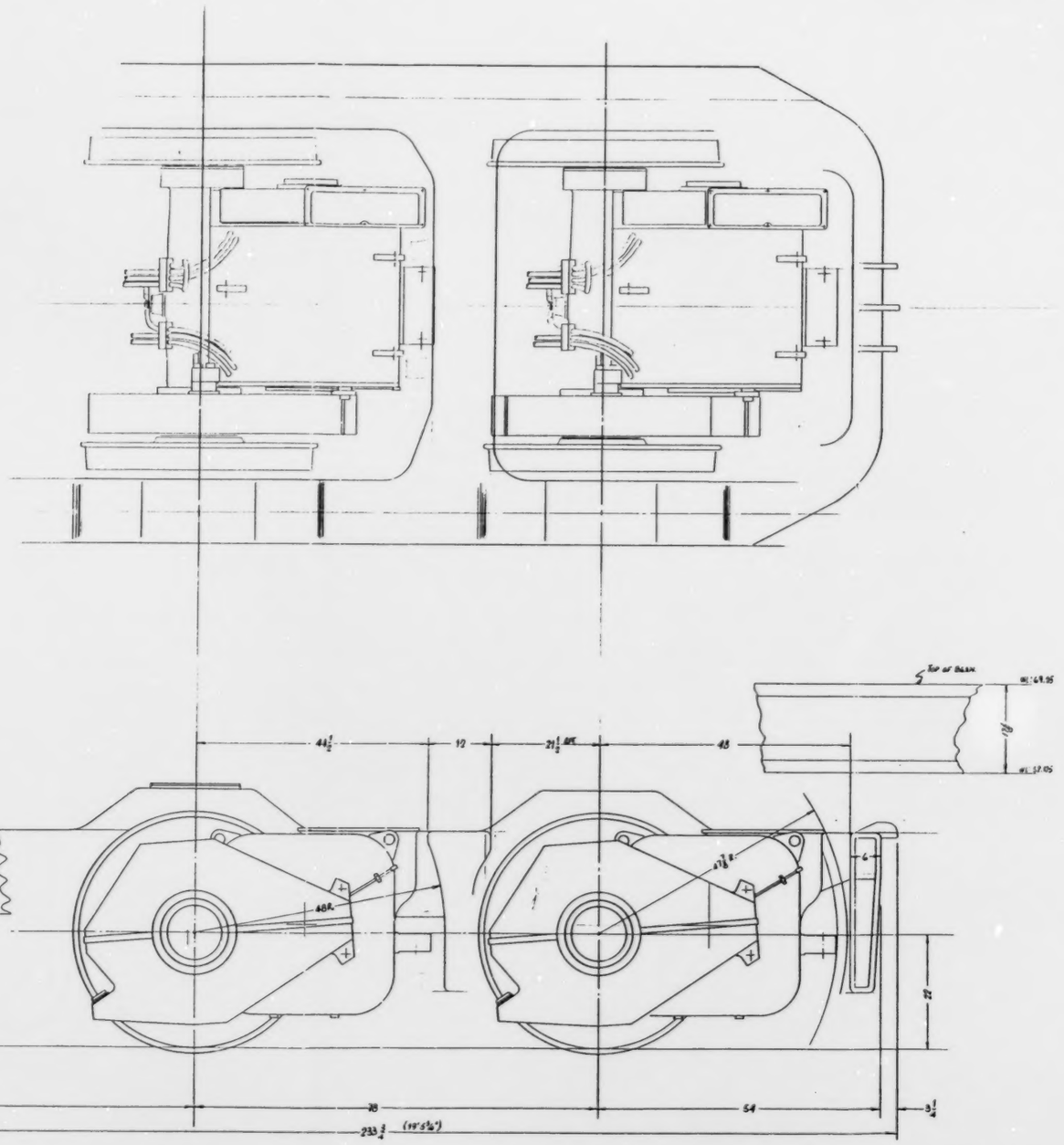
The GEC motor is larger than the CGE 752 motor and does not fit the space available in the existing trucks. In addition, 1118 mm (44 in) wheels are required for proper performance with a 87/20 gearset. An increase of between 127 mm (5 in), if the nose mounting of the motor is changed, and 279 mm (11 in), if the present motor nose suspension is retained, will be required in the axle-to-axle spacing to accommodate the motor. The worst case situation is depicted in Figure 27. In either case changes to the truck side frames will be required and, with this, a new truck design. The 1118 mm (44 in) wheel does not interfere with the transom and this part may not need to be redesigned. Similarly no changes are required in the frame beams.

5.3 Cabling and Air Duct Arrangements

On some existing diesel electric locomotives the frame channel formed by the floor beams and upper and lower plates form a duct for supplying cooling air to the traction motors. On the new design electric locomotive, blowers will be allocated on a per-truck basis and the enclosed frame area will serve both as a duct and as a conduit for the traction motor and other cabling. As considerably more cabling is required on the electric locomotive as compared to a diesel-electric the allocation of space in the enclosed frame area was examined carefully.

Figure 22c shows various sections through the C-C locomotive equipped with DC traction. Section BB shows the electrical connections to one of the equipment cabinets and the enclosure for traction motor air. Cabling between the transformer and other electrical equipment is shown in Sections CC and DD, whereby, in this area, no traction motor air ducting is required.

Figure 28 depicts an arrangement for traction motor cabling and air ducting in the forward truck. The section, taken at the high-voltage compartment (6), shows that the cabling is kept out of the air duct to avoid air leaks and sealing problems.



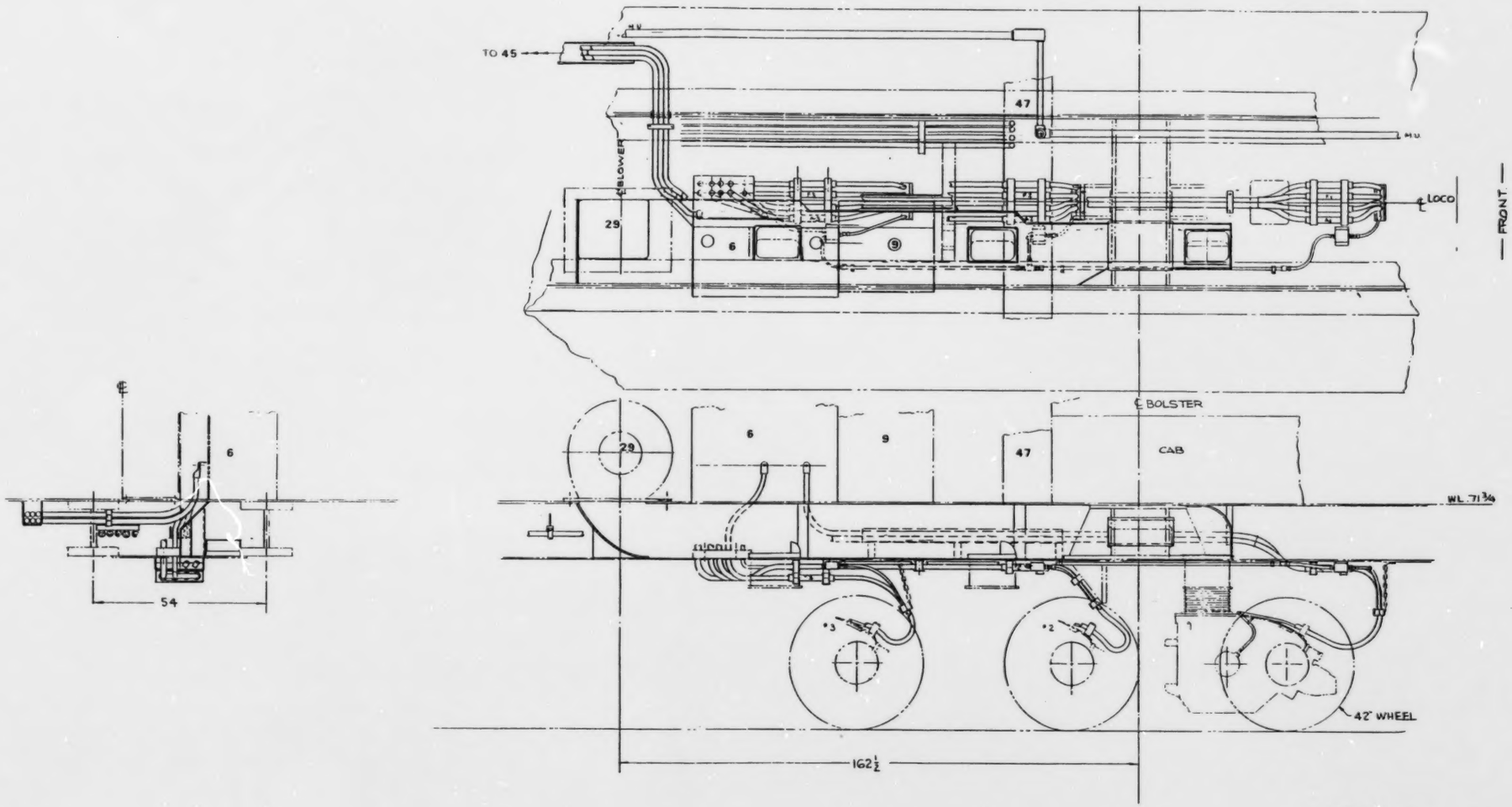
GEC TRACTION LTD
MOTOR # G 416 A2 DWG # 2002 X 2258

Figure 27.

Bombardier Inc.
Bombardier Inc.
Division des produits ferroviaires sur chassis
Rail and Chassis Products Division
Montreal Quebec Canada

MOTOR TRUCK ARRG'T
ELECTRIC LOCO
MSK-0-5938

ELECTRIC
439160
AO
1/6



NOTE:-
FOR IDENTIFICATION OF EQUIPMENT SEE
DRAWING Nº A98-095110-000

Figure 28.

Bombardier Inc.
Division des produits ferroviaires et d'acier
Rail and Steel Products Division
Montreal Quebec Canada

A98-095110-000

T.M. CABLE & BLOWER
DUCT ARRANGEMENT

A59-006300-050

A59-006300

5.4 Roof Structure and Support

The truss-frame type of locomotive construction is only required where special circumstances, such as weight limitations, dictate. Weight was determined not to be a problem for the C-C locomotive with either type of traction system. Since the conventional frame and hood construction is known to be less expensive than the truss-frame it was decided to adopt this construction for the new design electric locomotive layouts. Using this concept, the major considerations are:

- Weight load on the roof and stability.
- Requirement for removal of internal and roof-mounted equipment.

The electric locomotive roof must support the weight of the 50 kV electric components and resist the forces in all directions caused by the motions of the locomotive acting on these masses. Because of the requirement to conveniently remove roof sections it was not feasible to run longitudinal members through the entire roof area to gain stability.

The concept developed to satisfy the requirements was as follows (Figure 22a,b,c):

- Welded-down cab and DB hood for longitudinal structural support.
- Foot rails bolted to the deck supporting vertical members which, in turn, support intermediate and top rails to transmit longitudinal forces in the body.
- Carlines placed at three points along the length of the locomotive and composed of channels completely encompassing the locomotive body to take roof weight and other forces.
- Self-supporting roof sections (Section XX of Figure 22c) which rests on top rails and carlines, the attachments to which are conveniently accessible in order to facilitate removal.

5.5 Rotary Air Compressor

The piston-type reciprocating air compressor as used on diesel-electric locomotives is less suitable than the rotary screw type for use on electric locomotives. The standard piston type is sized to deliver sufficient train air at reduced engine speeds so would represent unused capacity even when driven by an electric motor. A smaller piston machine was not found to be available in the sturdy, low-speed construction characteristic of the unit presently used on diesel-electric locomotives.

Rotary screw compressors are available from a number of manufacturers and have been used on practically all North American electric locomotives of recent manufacture. A reconfiguration of an existing unit was carried out for installation into the various electric locomotive configurations studied.

The heat of compression must be removed from the oil circulating in the compressor. This is accomplished by an oil-to-air heat exchanger cooled by an electric motor-driven ventilating fan. The cooling air is drawn from the center area of the locomotive and exhausted through a side vent in the case of the C-C locomotive (Figure 22a). In the winter the exhaust air can be re-circulated by use of a damper.

In B-B configurations (Figure 23a) the complete compressor unit may have to be be mounted under the frame. Intake air would be obtained from the rear traction motor air duct in view of the dusty conditions existing under the locomotive.

A considerable reduction in space requirements for the compressor will result when units become commercially available in the power range suitable for electric locomotive applications (40...60 hp) designed with the air end mounted in the separator tank.

5.6 Auxiliary Power Systems

5.6.1 Introduction

The numerous auxiliary power requirements on an electric locomotive have to be satisfied by electric motor drives operating from one or the other of the following possible on-board power systems:

- 1-phase AC 60 Hz.

- rectified DC.

- battery-voltage DC.

- 3-phase AC.

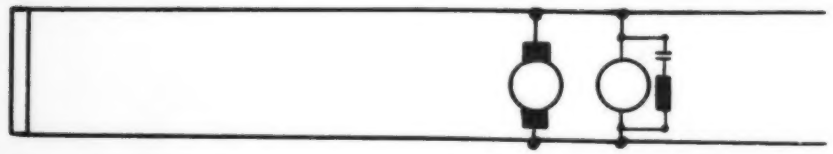
All on-board energy is derived from the 50 kV single-phase AC overhead through a separate winding on the main transformer. The various power systems are depicted conceptually in Figure 29. Electric locomotives will always have a battery-supported nominal 64 VDC system for essential loads such as the locomotive controls and auxiliary air compressor. The larger power loads would be connected to one of the other higher-voltage systems. The advantages and disadvantages of the possible drive motors for the various loads and the requirements on power transformation and control to support the power systems were studied and preliminary choices made for the various electric locomotive designs.

5.6.2 Single-phase AC 60 Hz

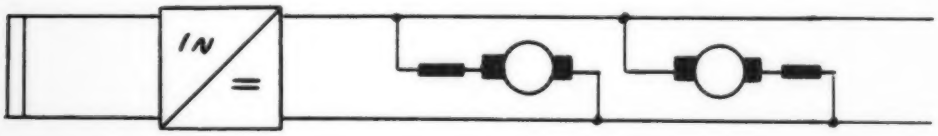
This system exists automatically at the output of the auxiliary transformer and, for some older electric locomotives, represented the only high-power auxiliary power system used. The fundamental disadvantage of the system is that the voltage available to auxiliary motors will vary proportionally with the catenary voltage. In view of the large voltage swings possible and the requirement to maintain auxiliaries operating satisfactorily under these conditions, appreciable over-dimensioning of the motors must be considered.

The single-phase motors used can be of the capacitor-start or capacitor-start/run type up to about 10 hp. This suffices for oil pumps and transformer cooling fans.

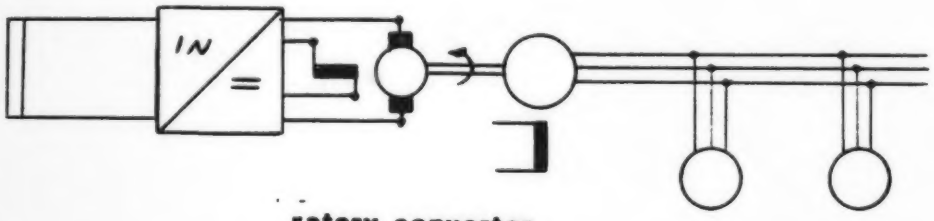
Commutator-type series-wound single-phase AC motors would be required for the traction motor blowers if driven from the single-phase supply. The availability of such motors in Canada could not be ascertained.



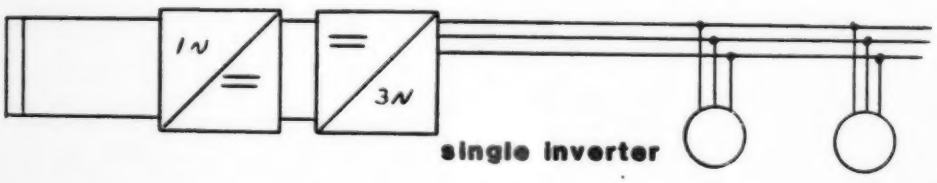
a) 1-phase AC motors 60 Hz



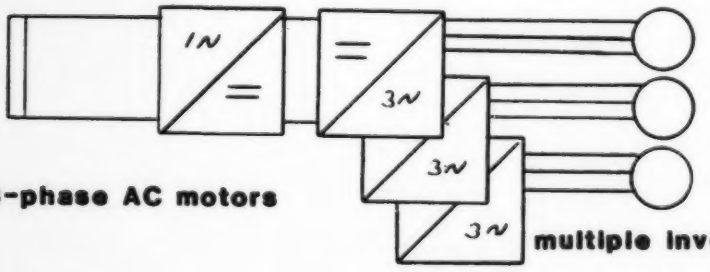
b) DC series motors



rotary converter



single inverter



c) 3-phase AC motors

multiple inverter

Figure 29. AUXILIARY POWER SYSTEMS

5.6.3 Rectified DC

A simple bridge rectifier can be used in conjunction with series-wound DC motors to drive the traction motor blowers. This type of motor is relatively insensitive to input voltage swings which, with a simple rectifier, would appear more or less directly on the motor terminals. The motor would absorb voltage surges on its series winding and not be subject to current surges and flashovers.

Alternately a shunt-wound motor can be applied whereby the rectifier would have to be reconfigured as a semi-controlled regulator.

DC motors are larger, heavier, and cost far more than the 3-phase AC squirrel-cage induction motor commonly used in industry. Moreover there may be a maintenance penalty connected with the use of such motors because of their commutators.

One area where the DC motor may be expected to continue to compete is as a DB grid blower drive. Here the DC power for the motor is derived from a tap across a grid resistor and is thereby not derived from the electrification system.

5.6.4 3-Phase AC

The 3-phase AC squirrel-cage induction motor is attractive for auxiliary drive use on an electric locomotive because of its simplicity, low maintenance, and reasonable cost. The motors must, however, be provided with 3-phase AC power from either a static or rotary converter.

The rotary converter typically consists of a synchronous alternator driven by a separately-excited DC motor. The DC motor is controlled in its armature and field by thyristor regulators enabling protection against line voltage surges and swings and load changes. The latter can be quite severe when across-the-line starting of the loads is used. The output power would normally be maintained at constant frequency and voltage. Speed changes in auxiliaries, if desired, would necessitate some form of winding control on the motors.

Static converters are available in a number of configurations for changing the single-phase AC input power into 3-phase AC output power. In its simplest form a static converter will essentially replace a rotary converter by setting up a constant-voltage/constant frequency output power system. With relatively minor adaptations the output system can be arranged to give one or more additional discrete voltage and frequency states whereby the ratio of these two quantities would be held constant in order to protect the motors.

More sophisticated configurations can be used to provide a number of individual power systems for the various motors. In one system auxiliary motor drives associated with each truck are connected to separate converters while a third converter is used to supply common loads (air compressor, oil pumps). The system could offer even more enhanced operational security if switchgear is provided to switch the common loads from their possibly defective converter to one of the truck-based units. The tractive capabilities of the locomotive could be halved in this case but the locomotive would not be stranded.

5.6.5 Auxiliary Power Systems Selected for Canadian Electric Locomotives.

The system selected for inclusion on layouts for electric locomotives equipped for DC traction was the GEC single static inverter supplying constant output frequency and voltage. This is an oil-cooled thyristor unit similar in technology to the converter and capable of across-the-line sequential starting of the various motor loads.

For the locomotives equipped with BBC 3-phase AC traction a triple inverter solution was selected. These are air-cooled transistor/thyristor units capable of output voltage/frequency regulation. The allocation of motor loads is as follows:

Converter #1	#2	#3
Tract.conv. oil pump #1	Tract.conv. oil pump #2	Compressor
Tract.mtr. blwr. #1	Trac.mtr. blwr. #2	DB blwrs
Oil cooler fan #1	Oil cooler fan #2	Transf. oil pump
		Other loads

Switchgear would be provided to shift load from auxiliary converter #3 to #1 or #2 (and disconnect the original loads) in the event of failure of #3.

The use of 4-quadrant controllers enables use of locomotive braking energy in the various auxiliaries without draw of power from the electrification system until quite low locomotive speeds are reached.

5.7 Traction Power System

5.7.1 Introduction

The traction power system on a modern electric locomotive destined for North American service at 50 kV, 60 Hz would be restricted to one of the following traction power systems:

- DC with series DC traction motors.
- DC with separately-excited DC traction motors.
- 3-phase AC with synchronous motors.
- 3-phase AC with asynchronous motors.

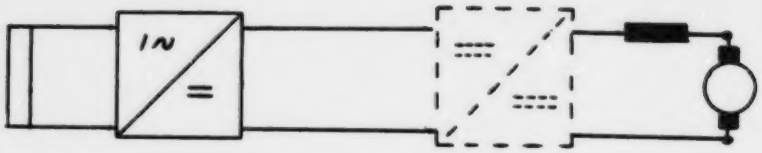
These possibilities are depicted conceptually in Figure 30 whereby an attempt has been made to differentiate between the traction motor and input circuit.

The starting point for all these concepts is the main traction windings of the power transformer, whereby one or a number of windings may be used in series depending on the traction alternative being considered.

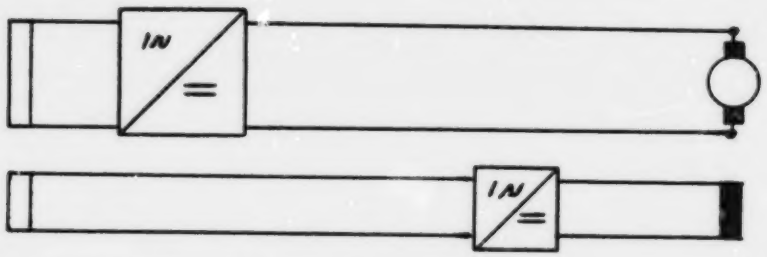
5.7.2 Traction Alternatives Using DC Traction Motors

A simple and effective concept, closely related to diesel-electric locomotive practice, is depicted in Figure 30a. The series DC traction motor is directly controlled over the armature voltage by variation of thyristor opening angles in the semi-controlled input bridges. Typically the motors in each truck are controlled in parallel by a separate controller for each truck. Three bridges (and associated windings) may be connected in series to improve power factor since the phase delay control will extend throughout the entire locomotive speed range with a series motor.

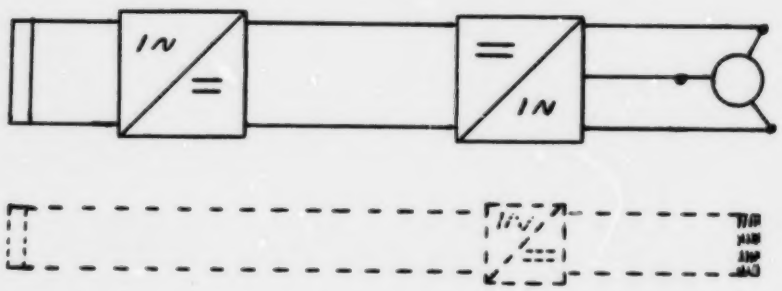
INPUT CIRCUIT MOTOR CIRCUIT



a) DC series motor



b) DC separately-excited motor



c) 3-phase AC motor

Figure 30. TRACTION POWER SYSTEMS

Further power factor improvement is provided by on-board capacitor banks switched in and out by thyristor switches as a function of locomotive speed and current draw. Alternately, one of the bridges may be configured for forced commutation which acts to force the current waveform into phase with the line voltage.

If individual motor control is desired, DC-DC choppers can be provided following the input controller as shown dashed in Figure 30a. In this case the input controller can be simplified to two semi-controlled bridges (and windings) each feeding the individual choppers associated with the traction motors in each truck. Disturbing current is minimized and power factor maximized because the locomotive will look like a rectifier locomotive to the power system.

Individual axle control is inherent to the circuit shown in Figure 30b which is used to supply separately-excited traction motors. Armatures are usually grouped and controlled on a truck basis while field control allows individual motor current adjustment. Armature control is used only in the low speed portion of the locomotive speed range, above which only field weakening is applied and the locomotive appears to the line like a rectifier locomotive.

The power capabilities of DC traction motors when constrained by the space available in presently available motor trucks equipped with 1067 mm (42 in) wheels is on the order of 1000 diesel-equivalent hp.

5.7.3 Traction Alternatives Using 3-Phase AC Traction

Given the truck space constraints presented in Section 5.2 above the only possibility of increasing installed power is to utilize the available space more efficiently. In this regard synchronous 3-phase AC traction motors provide only a limited advantage since the slip rings (or rotating rectifier as an alternative) require some space which reduces active iron length. No response was received from companies developing this technology to the request for motor designs to fit the existing trucks.

A presently available 3-phase AC asyncronous traction motor can handle 1000 diesel-equivalent hp and fits into existing North American trucks. With possibly improved insulation the motor could handle higher applied voltages and, hence, work to higher power levels.

The input and motor circuit for use with 3-phase AC motors is shown in Figure 30c, whereby the dashed portion represents the additional field controller required in connection with synchronous motors.

The inverter shown can be either of the voltage-source or current-source type. For the former the intermediate DC circuit will contain capacitors while the latter will incorporate an inductance to reduce power pulsations from the input controller.

The input controller will differ depending on whether voltage-source or current-source inverters are used; in the former case the controller will act to regulate system voltage to a constant value despite line swings. The input controller for use with current-source inverters generally takes on the current regulation function. The input controller for the voltage-source inverter can be configured as a 4-quadrant controller capable of regenerating energy to the line. This is also possible with the other controllers to some degree over part of the locomotive speed range but has been rarely implemented.

5.7.4 Traction Systems Selected for Canadian Electric Locomotives.

The GEC standard of separately-excited DC traction motors with individual axle control was selected as the primary conventional system choice for C-C Canadian electric locomotive of up to 6000 diesel-equivalent hp. The trucks must be modified to accept the existing GEC traction motor and would require 1118 mm(44 in) wheels. Limitations on the existing traction motor would restrict a B-B electric locomotive to about 4000 diesel-electric hp. Full utilization of the traction capability on a B-B to 5000 hp would require a larger traction motor.

For 3-phase AC traction a traction motor already exists for 1000 diesel equivalent hp suitable for installation in an existing motor truck. A C-C locomotive is therefore feasible without truck changes. According to the manufacturer it may be possible to achieve at least 1250 diesel- equivalent hp from the same motor by increasing its voltage and thereby achieve a 4-axle 5000 hp Canadian electric locomotive.

The input controller used for locomotive layouts with 3-phase AC traction was of the 4-quadrant type. While such controllers work admirably on European 16-2/3 Hz systems the 60 Hz line in North America results in a significant derating of their power-handling capacity. This coupled with the low overall population density along the projected routes and the heavy trains and infrequent scheduling of train operations common to North American railroading reducing the benefit of regeneration points to the initial use of the more conventional semi-bridges as a 3-phase AC traction input controller.

5.8 Weight Study

An in-depth weight study was conducted for the C-C electric locomotive with conventional DC traction. There is a requirement for at least 60,000 lbs of ballast on this locomotive. As this would be less than the added weight of 3-phase AC traction equipment, a C-C unit with 3-phase AC traction would be equally feasible.

The following steps are required in carrying out the weight study using a computer simulation program:

- enter all concentrated weights and their location on the frame into the program.

- enter all distributed weights and lengths over which they are applied.

At this point a print-out is obtained of the shear force and bending moment at the various frame stations. Figure 31 depicts the condition for the assumed loading of the C-C electric locomotive. There was equal loading of both trucks to within 1%.

- enter beam flange dimensions.

- enter expected traction and buff forces, dynamic factor, and material properties.

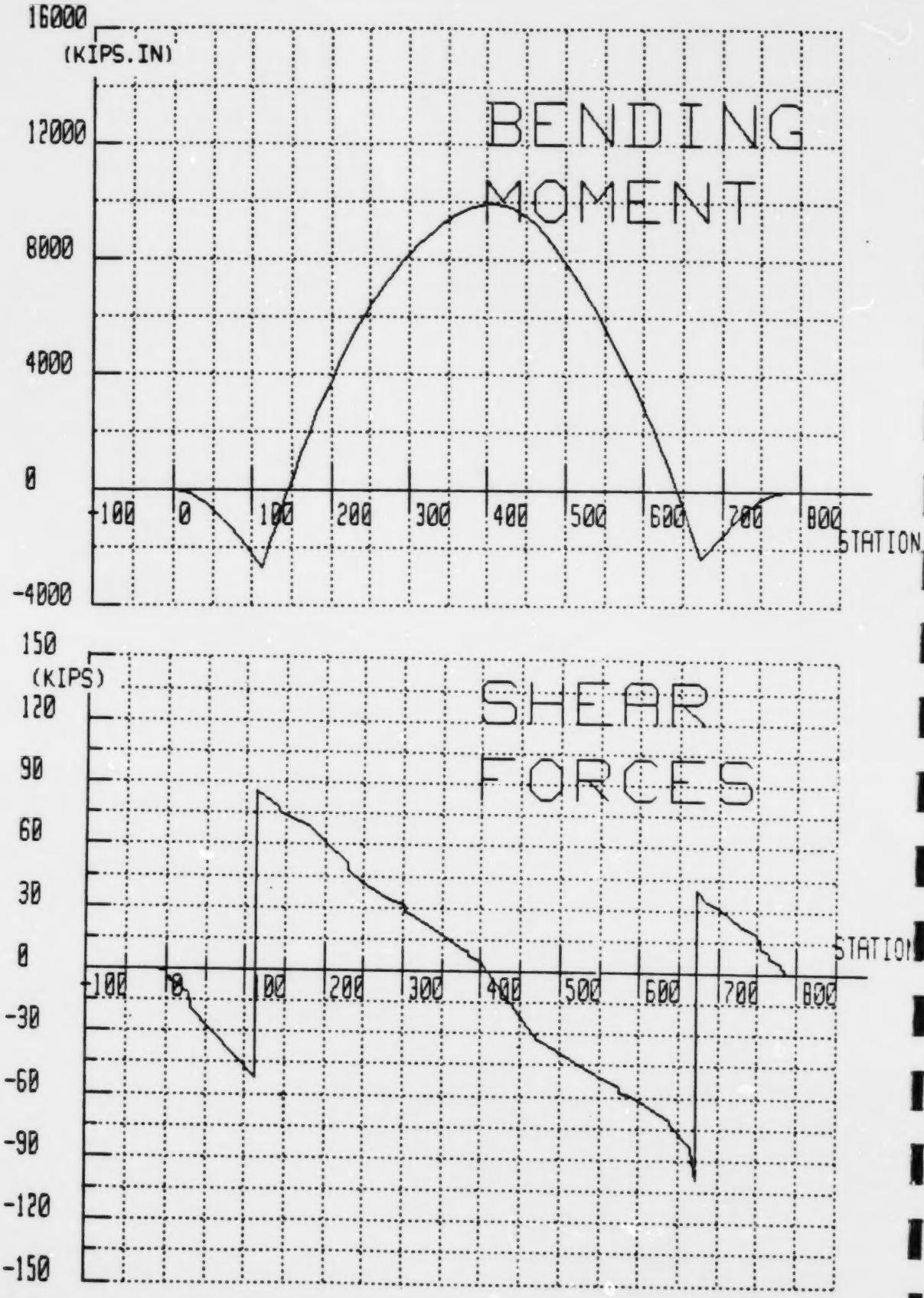


Figure 31. Shear and Bending Moment

The program responds by calculating the minimum beam web thickness and the safety factor available in traction and buff.

- enter the web thickness.

The deflection of the locomotive frame is calculated at the ends of the locomotive and at its center of gravity. The deflection at the latter point is about 29 mm (1.15 in) for the C-C locomotive. During construction of the locomotive a camber of this amount would be preset into the frame so that when loaded with equipment the locomotive would have a level deck.

6. MISCELLANEOUS INVESTIGATIONS

6.1 Manufacturing Inputs to the Locomotive Layouts

A manufacturing methods group was involved during the locomotive layout work to ensure manufacturing inputs to the designs. A walk-through of the expected production sequence was conducted and the capabilities of the various production machinery assessed.

The major concerns of the methods group were:

- design to ease manufacturing complexity and cost both in labor and material.
- consideration of accessibility for installing and removing equipment.
- organization of the locomotive construction work steps such that modules can be assembled in a number of areas remote from the locomotive.

6.2 Cost Comparison

A rough comparison of shop man-hours was made based upon the preliminary layout of a C-C electric locomotive and a diesel electric locomotive of similar size. The most significant differences were identified in the extra labor required to manufacture and install the fuel, lube oil, and cooling water systems peculiar to the diesel engine. Structural, carbody, cab, and running gear components remain essentially the same cost whether for electric or diesel electric locomotives. Hence it can be stated that the initial cost of an electric locomotive without the electrical equipment would be significantly less than a diesel electric without its electrical equipment. The prices for the electrical equipment were not requested at this time since considerably better equipment definition will be required before estimates can be made.

6.3 Test Track Electrification

In order to check out the locomotive traction and auxiliary systems a source of 50 kV AC will be required for any test track whether existing or new. A possible 50 kV equipment installation was investigated by Plant Engineering with the assistance of a representative from Electrak, Canada.

It was determined that a portion (approximately 1000 ft) of the test track can be conveniently electrified at 50 kV at a reasonable expense. Existing pole lining the track can be used as supports for a single wire overhead supply

An area can be prepared for convenient and secure outdoor installation of a 50 kV substation. Since the short length of the test track will hold locomotive speeds to low values an installed power on the order of 500 kVA will suffice for locomotive check-out activities.

7. CONCLUSIONS

This study has led to the following conclusions:

1) PERFORMANCE

Future Canadian electric locomotives will work on a 60 Hz electrification system at nominal voltage levels of 50 kV. Operation at 25 kV at reduced performance may be required in restricted areas. Voltage swings are likely to be very pronounced given the high point loads associated with operating few but very powerful trains from a system with widely separated substations. It is important that the electrification system not be designed around a particulaly advantageous form of locomotive traction system. It must, instead, incorporate sufficient reserve such that locomotives with differing traction systems will perform adequately on the system.

Electric locomotives operating on future Canadian mainline electrified railroads will work at continuous and short-time low speed tractive efforts not significantly superior to those of the most modern available diesel-electric locomotives now produced. The load to be hauled will be dictated by dispatching practices and it would make no sense to install more tractive effort than can be reliably exploited on a day-to-day operating basis.

The performance advantage of the electric locomotive over the diesel-electric resides in its capability to hold the continuous and short-time tractive efforts to high speeds resulting in a much higher power capability both continuously and short-time.

The benefits to the railway operator of the increased power capability are in lower travel time and increased volume of merchandise carried and/or fewer locomotives required. To what degree these benefits accrue is a strong function of railroad topography and operating practices. Analysis of the mainline Canadian railroad scenario leads to the conclusion that for C-C electric locomotives approximately 6000 diesel-equivalent hp would represent a broadly optimum solution. The value for B-B electric locomotives would be about 5000 hp.

2) LOCOMOTIVE CONFIGURATIONS

The basic dimensions of a future Canadian mainline electric locomotive are similar to those of existing diesel-electrics except as modified by the presence of the 50 kV overhead electrification. B-B locomotives will, as a consequence, have a lowered roofline over their entire length. C-C locomotives may have lower roofline overall or, alternately, a locally-lowered roofline and a full height cab depending on operator preferences.

In the present length of Canadian B-B and C-C locomotives sufficient space is available in the body of the locomotive for installation of either DC or 3-phase AC traction equipment up to a continuous power rating of 6000 diesel-equivalent hp.

A C-C electric locomotive could have any of the following configurations:

- "CN" cab with wide carbody (continuous or tapered).
- Single or dual "Euro" cab with wide carbody.
- "CN" cab with narrow long hood.

A B-B electric locomotive would be limited to the following configurations:

- "CN" cab with continuous wide carbody.
- "CN" cab with narrow long hood.
- Single "Euro" cab with wide carbody.

3) LOCOMOTIVE EQUIPMENT

Roof arrangements for 50 kV equipment have been realized capable of satisfying all foreseeable operator requirements.

In all cases except, possibly, the DB blower drive, Canadian electric locomotives would utilize 3-phase AC induction motors in auxiliary drives. Supply would be from either a single inverter or a group of inverters.

In the area of 3-phase AC traction BBC, Canada cooperated to develop a traction system configuration based on already-existing equipment. In particular, a traction motor is available to fit existing trucks and capable of the required performance on B-B and C-C locomotives.

GEC has cooperated in the area of conventional DC traction. GEC equipment presently exists that will satisfy the performance requirements of B-B and C-C Canadian electric locomotives with the exception that changes to the existing trucks will be required.

Truck changes to accomodate the GEC motor, a larger BBC motor and/or larger wheels up to 1295 mm (51 in) were identified.

4) LOCOMOTIVE SPECIFICATION

A general specification pertinent to all the potential Canadian electric locomotive configurations and propulsion alternatives has been developed.

5) FUTURE WORK RECOMMENDATIONS

The continuation of further design work on Canadian electric locomotives will depend on the probability and immediacy of large-scale electrification in North America. Work would be oriented to that locomotive configuration best suited to the potential operator's requirements.

A test track would be electrified for locomotive checkout and arrangements made with existing 50 kV railroad operators for performance testing on their trackage.

A prototype locomotive would be constructed and tested in advance of the request for proposals in order to qualify as an eligible bidder.

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APPENDIX A

CANADIAN MAIN-LINE ELECTRIC FREIGHT LOCOMOTIVE SPECIFICATION

INTRODUCTION

This specification defines the general requirements pertinent to the design of Canadian electric locomotives for use in North America. The specification shall apply to B-B and C-C type electric locomotives for operation on 50 kV AC 60 Hz electrification systems. The locomotives shall be general purpose, suitable for use individually and in consist in heavy-duty general freight and unit train applications.

LOCOMOTIVE DESCRIPTION

The locomotives will be designed and built to meet the requirements of modern freight service in North America. The locomotives receive electric power from an overhead 50 kV AC 60 Hz contact wire through a pantograph, of which either one or two may be provided. The power is transformed and converted into current suitable for operating either four or six railway-type traction motors. Each motor drives its corresponding axle through individual gearboxes.

Each wheelset is provided with brake shoes operated by a pneumatic brake system.

Traction and braking forces are transmitted from each of two 4 or 6 wheel trucks to the frame of the locomotive. The forces are carried through the draft gear and coupler to the attached train.

The frame carries the complete equipment load and traction and buff forces. Narrow, full-width, or tapered full-width hoods are provided to house the locomotive equipment. The hoods support the weight of detachable roof sections and associated equipment.

The locomotive is bi-directional and can be operated from a standard master controller or, alternately, from desk control handles. Either one "CN"-type cab or, alternately, one or two (C-C versions only) "Euro"-type cabs can be provided.

PERFORMANCE

Electrification Suppply

Nominal	50 kV
Maximum	55 kV
Minimum	30 kV
Frequency	60 Hz

Operation on 25 kV nominal electrificatoin shall be possible, if required, by addition of transformer tap switches.

Gauge

1435 mm
4 ft 8.5 in

Axle Configuration

B-B C-C

Locomotive Weight (Max.)

B-B	C-C
127 t	191 t
130 tons	195 tons

Axle Loading

32 t
35 tons

Low Speed Continuous Tractive Effort at Rail

B-B	C-C
324 KN	485 kN
72,800 lbs	109,000 lbs

(for line voltages in the range 30 kV to 55 kV)

Continuous Power Rating at Rail

B-B	C-C
3170 kW	3810 kW

(at 50 kV line voltage)

Maximum Speed

113 km/h
70 mph

Power Factor

.75 minimum
(average value for range of 40% to 100% of output power)

Efficiency

.85 minimum
(average value for range of 40% to 85% of output power)

Electric Brake Power Rating at Rail

	B-B	C-C
Dynamic	2990 kW	3730 kW
Regenerative	not required	

Psophometric Current

16A peak
14A (average value for range of 40% to 80% of output power)

Harmonics

5% maximum
(voltage distortion on 138 kV primary with 1000 kVA minimum system.

LOCOMOTIVE DIMENSIONS

	B-B	C-C
Maximum Length:	18593 mm 61 ft	21336 mm 70 ft
Width Overall:	3175 mm 10 ft 5 in	
Height Overall:	4293 mm 14 ft 1 in	4591 mm 15 ft 1 in
Pantograph Lockdown Height:	5194 mm 17 ft 1 in	
Truck Wheelbase:	2845 mm 9 ft 4 in	2 X 1701 mm 2 X 5 ft 7 in
Wheel Diameter (new):	1067 mm 42 in	

OPERATING CONDITIONS

The locomotive shall receive, transmit, and store alarm, control signals, and other trainlined information in order to work satisfactorily in a lead or trailing position in a locomotive consist.

Number of Locomotives in Multiple Unit:
5 maximum

Ambient Air Temperature Range:

$-40^{\circ}C$.....+ $40^{\circ}C$
$-40^{\circ}F$.....+$104^{\circ}F$

The indicated temperatures can occur in the altitude range of:

0 ... 1200 m
0 ... 3937 ft

Minimum Exposure Temperature:

The locomotive and its equipment may be exposed to temperatures as low as $-50C^{\circ}$ ($-58^{\circ}F$) at times. Operation of the equipment is not expected under these conditions.

Pollutants in cooling air:

snow
moisture
dust
engine exhaust
coal, mineral, farm produce blow-off

Submerged Track:

The locomotive may travel through areas where water will have accumulated to a height of 76 mm (3 in) over the top of rail. The maximum speed of the locomotive in these areas will not exceed 5 km/h (3 mph).

Utilization:

The locomotive can be expected to have the utilization as shown in the following table:

Percent of locomotive lifetime at each notch	Notch
46	Stand-by
4	1
4	2
4	3
4	4
4	5
4	6
4	7
4	8
9	DB

Shock and Vibration:

The locomotive body will be subject to the following shock environment:

- vertical - 5g
- longitudinal - 3g
- lateral - 3g

The shock environment in the truck shall be as follows:

- vertical - 10g
- longitudinal - 6g
- lateral - 6g

Ballast, ice pieces, and debris can impact truck-mounted equipment in the direction of motion at up to 120 km/h.

The shock environment at the axle shall be:

- vertical - 50 ... 100g
- longitudinal - 6g
- lateral - 20g

The motor housing shall be designed such that, in the event of a derailment resulting in a load of 32 t resting on the frame, the active iron portion of the motor will not be damaged.

EQUIPMENT REQUIREMENTS

TRACTION SYSTEM:

Traction Motors: 4 or 6 traction motors shall be furnished. Motors shall be either:

- DC separately-excited
- 3-phase AC asynchronous

Motors shall be force-ventilated with filtered cooling air. Roller bearing suspension on the axle shall be standard.

Traction Drive: Single stage gearing shall be used for traction drive from each motor to its associated axle. The gear ratio shall be appropriate to the type of traction motor used and give long gear life.

Power Conversion:

For DC traction individual axle control shall be applied. Separately-excited motors shall be armature-controlled on a truck basis and be provided with individual field controls.

Switched-capacitor power factor correction using thyristors shall be applied.

Asynchronous motors shall be controlled on a per-truck basis from individual inverter supplies or, alternately, individual axle control shall be applied.

The inverters shall be preceded by an input regulator of the 4-quadrant controller type for power factor correction or, alternately, utilize switched-capacitor power-factor correction. Power conversion equipment shall be directly air-cooled or use heat exchangers for oil cooling of the power semi-conductors.

Electronic Control:

Micro-processor based electronic controls shall be used to:

- regulate traction motor tractive and braking effort.

- provide protection and diagnostic functions.

- provide overlaid controls to include train-line interpretation, speed control, and weight transfer correction.

Switchgear: Electropneumatic switchgear shall be used to provide circuit separation and protection functions. The 50 kV circuit breaker shall be of the vacuum type.

Provision shall be made to cut out traction motors on an individual basis with DC traction. With 3-phase AC traction both traction motors and associated inverters shall be disconnectable.

Transformer: The transformer shall be suitable for traction service and be of welded, robust construction. Oil cooling of the windings shall be used with the oil-to-air heat exchangers mounted externally on the transformers for forced ventilation with unfiltered air.

Reactors: For DC traction a motor smoothing choke shall be supplied for the motors of each truck. For 3-phase AC traction a 3-phase AC reactor shall be used for the motors of each truck. In either case these components shall be air-cooled.

Lightning Arrestor:
A lightning arrestor shall be supplied for roof mounting in order to protect equipment against lightning and switching surges.

Dynamic Brake: A roof-mounted dynamic brake pod shall be used to dissipate heat resulting from electric braking. This shall consist of two or three sets of brake grids cooled by separate axial blowers driven by 3-phase AC induction motors. Alternately, an arrangement shall be supplied using a DC motor-driven radial blower supplied from a tap on the brake resistors.

AUXILIARY POWER SYSTEM:

Induction motor drives shall be provided for the following functions:

- traction motor blowers
- air compressor drive
- oil-to-air heat exchanger fans for transformer and air compressor
- oil pumps
- DB grid blowers (DC motors optional)
- dust bin blowers (where provided)

Motors shall be 480 V, 60 Hz, 3-phase with pole-changing capability for reduced speed operation, where required, and where inverter frequency changing is not applied.

The auxiliary power system shall be supplied from a single inverter (on locomotives equipped for DC traction) or 3 inverters (on locomotives equipped for 3-phase AC traction). The inverter(s) shall be capable of continuously supplying auxiliary loads, to include the low voltage converter, at 35 kV input voltage.

A 32-cell lead-acid type, 280 ampere-hour storage battery shall be furnished to supply power for control logic, lights, and other auxiliaries.

UNDERFRAME AND RUNNING GEAR:

Axles	Axles shall be solid forged steel, conforming to AAR material specifications.
Wheels	Wheels shall be Class BR, multiple wear, rolled steel wheels with 42 in diameter and AAR tread and flange contour.
Journals	Journals shall be equipped with sealed grease-lubricated roller bearings. Pedestal openings of the truck frame shall have renewable non-metallic wear plates.
Trucks	The running gear of the locomotive shall consist of two swivel trucks.

Locomotive weight shall be supported by four rubber mounts which rest on the truck frame and provide controlled lateral motion. The truck frame shall be supported by alloy steel coil springs over the journal boxes.

Hydraulic shock absorbers shall be used to damp vertical oscillation and body lateral motion. The truck shall be of cast steel, designed for minimization of weight transfer.

In the 4-wheel version chevron pads shall be used to transmit motoring and braking forces to the locomotive body. In the 6-wheel version the truck pivot shall engage elastic members attached to the locomotive frame.

Truck safety cables shall be provided to minimize slewing in case of derailment and to permit the trucks to be lifted with the superstructure.

FRAME:

The frame shall be constructed of fabricated steel sections and plate.

Space between these members is enclosed to form air ducts which distribute clean air throughout the locomotive.

Four jacking pads in combination with lugs for cable slings shall be provided. Lifting lugs shall also be provided at both ends of the underframe for lifting one end at at time.

BRAKE EQUIPMENT:

Brake cylinders shall be mounted on the truck frames to operate fully equalized brake rigging, which applies one composition brake shoe to each wheel. Brake rigging shall be furnished with hardened steel bushings and adjustments provided to compensate for wheel and shoe wear.

A hand brake shall be provided that applies the brakes to two wheels of the front truck. The rear truck shall also be equipped with the necessary levers to be interchangeable with the front truck.

Sufficient braking power shall be developed to hold the fully loaded locomotive on a 3% grade when an actual force equivalent to 125 lbs is applied at the rim of the 20-in diameter brake wheel.

Air brake shall be 26L brake schedule including self-lapping independent with special 26F control valve portions. The following features shall be provided:

1. P2A valve and PC switch for service application.
2. Dead-man control.
3. Removable independent brake valve handle.
4. Removable automatic brake valve handle.
5. Three-position cutout cock on brake valve (out-frt-pass) with "F" control valve set for graduated release.
6. A-1 charging valve and two No. 8 vent valves including automatic 30 second timed sanding for emergency applications.
7. A C1 suppression valve.

Two 18" diameter x 120" reservoirs shall be mounted beneath the underframe with a total capacity of 59,000 cu in. Both No. 1 and No. 2 main reservoirs shall be equipped with filters and the main reservoirs shall drain using electronic timers.

One, 3-phase AC motor driven, single-stage, positive displacement, oil flood lubricated rotary compressor delivering 240 CFM at 1750 RPM input shall be provided, to incude a 2 stage air/oil separator, and an air-to-oil heat exchanger. Compressor air intake shall be filtered by paper filters.

Two operating speeds shall be provided. The lower speed shall be 875 RPM providing 120 CFM of air flow at 140 psi.

The electric air compressor governor shall be adjusted to maintain reservoir pressure between 130 and 140 psi.

Four sand boxes with a total capacity of 56 cu ft shall be supplied. Sanding systms shall be controlled electrically by a solenoid valve. Manual sanding switch or automatic sanding in power shall operate eight single line sand controllers, (four controllers for forward movement and four controllers for reverse movement). A separate switch shall be provided for lead axle sanding only. Sand controller cutoff valves shall be standard and outside access provided for trap maintenance.

Conductor's emergency valve shall be provided on the back of the control stand or, alternately, on left desk side.

4-1/2" duplex air gauges with gauge test fittings shall be provided. Test fitting shall also be supplied at compressor unloader switch.

An electrically controlled conductor's air signal whistle shall be provided in each operator's cab.

COUPLER:

Coupler shall be AAR type F bottom-operated interlocking type with rubber-cushioned draft gear. Alignment control shall be provided at each end of the locomotive.

HOODS:

Hoods shall be constructed of carlines designed to carry the weight of roof-mounted equipment. Panels shall be attached to carlines to form a tight, even hood under all conditions of frame flexing; panels shall not carry structural forces.

In narrow hood configurations openings shall be provided for equipment access. In all configurations air intake and exhaust openings of sufficient size shall be provided for the air quantities handled.

Roof sections with associated equipment shall be easily removable by overhead crane. On 4-axle locomotives 4 sections shall be provided; on 6-axle units 5 sections.

CABS:

The sides and roof of each operator's cab shall be insulated and steel-lined. The floor, raised above the underframe, shall be covered with 1/2" thick flooring.

The cab shall have safety glass windows in the front and sliding safety glass windows equipped with latches on each side of the cab. All other windows shall be fixed.

Doors on both sides of the operator's cab shall provide access to the cab. The doors shall have windows, weather stripping and locks. Doors in the rear of the operator's cab provide access to the equipment cab.

Depending on the cab arrangement two or three, slide rail mounted seats equipped with back rests and arm rests shall be furnished. Cushioned arm rests shall be provided at side windows. Jump seats shall be attached to the cab rear wall as an option. Four adjustable-type sun visors shall be installed in each cab.

A toilet suitable for locomotive use shall be provided either in the short hood or body of the locomotive.

A radio handset shall be installed in each operator's cab.

A water cooler shall be provided in each operator's cab together with cup dispenser.

Two air-operated windshield wipers on both sides of each operator's cab shall be provided.

Number boxes and classification lights shall be provided on each end of the locomotive.

Two, stationary, cast iron bells with air-operated ringer and operating valve shall be furnished.

One, five tone horn shall be mounted on each end of the locomotive.

Two, twenty pound carbon dioxide fire extinguishers shall be furnished, one in each operator's cab. Two, thirty pound dry chemical extinguishers shall be provided in the equipment cab.

Headlights shall be furnished at each end of the locomotive, each consisting of two, 200 watt, 30-volt, sealed-beam lamps. Dimming control shall be provided in each cab.

Lights and outlets shall be located as follows:

- Ceiling cab lights
- Equipment cab lights
- Gage lights
- Step lights by each ladder
- Outlet receptacles in equipment cab and operator's cab.
- Number lights at both ends
- Classification lights on both ends

A standard AAR operator's control stand or, alternately, an operator's desk shall be furnished with motoring, dynamic braking and reverse levers, automatic and independent brake valves, horn valve, and bell ringer valve.

The following devices shall be located within easy reach of the operator at his station: headlights, gauge lights, sander and power source changeover switches, pantograph up switch, and the window wiper valve. Warning lights shall be easily viewed on the control stand or operator's desk.

Control light and set-up switches are mounted on the rear cab wall.

A speed indicating system shall be provided to consist of four speed indicators (mounted on both sides of each operator's cab), and a speed recorder mounted in the control compartment.